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RENOVATION OF SECONDARY EFFLUENT FOR REUSE AS A WATER RESOURCE

Louis T. Kardos, et al

Pennsylvania State University

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16. Abstract Sprinkler application of chlorinated secondary sewage effluent at levels of 1 or 2 in/wk during the growing season or year-round increased crop yields and forest tree growth except for red pine at the 2 in/wk rate. Harvested crops removed large amounts of nitrogen and phosphorus, the two key eutrophication nutrients. N and P content of forest foliage was increased but the nutrients were recycled through the litter. NO_3-N in suction lysimeter samples at 4 feet were less than the U.S.P.H.S. limit of 10 mg NO_3-N/1. except in the growing season-2 in/wk red pine on Hublersburg silt loam and year-round, 2 in/wk hardwood on Morrison sandy loam, where the values were 2 to 4 times the U.S.P.H.S. limit. P conc. in the same samples was no greater than in untreated control areas and had decreased 98 to 99%. Only one deep monitoring well showed higher NO_3 and Cl^- conc. definitely ascribable to the effluent irrigation but still met U.S.P.H.S. drinking water standards. Recharge within one 43.5 acre site was estimated at 65 million gallons per year and resulted in lower pumping costs in two nearby University water supply wells. Annual costs of a sprinkler irrigation system to recycle sewage effluent through the land as a living filter were estimated to range from $13/EDU for 1MGD to $8/EDU for 10MGD. Data are also reported on hydrologic studies, boron studies, aeration studies, phosphorus adsorption studies and soil chemical changes. (EPA)

17a. Descriptors *Wastewater treatment, *~~Living~~ filters, *Sewage effluents, *Land disposal, *~~Waste~~water reuse, *Phosphorus removal, *Water pollution, Nitrates, Boron, Groundwater recharge, Sprinkler irrigation, Crop production, Tree growth, Oxygen diffusion, Exchangeable cations, Bray phosphorus, Nutrient removal efficiency, Monitoring, Suction lysimeters, Trench lysimeters, Piezometers, Runoff, Deep wells, Annual costs, *Pennsylvania

17b. Identifiers ~~Corn (grain),~~ Corn (silage), Reed canarygrass, White spruce, Red pine, Hardwoods, *Hublersburg clay loam, *Morrison sandy loam, *State College (~~Pa.~~ Penn)

17c. COWRR Field & Group 05D, 05E, ~~05F, 05B, 04B~~, 03C, ~~02G~~.

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February 1974

RENOVATION OF SECONDARY EFFLUENT FOR REUSE AS A WATER RESOURCE

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ABSTRACT

A 500,000 gallon per day supply of chlorinated, secondary treated wastewater was applied through sprinkler irrigation systems to a combined acreage of approximately 70 acres of cropland and forestland in variously located experimental plots on Hublersburg silt loam or clay loam soils or on Morrison sandy loam soil. The hydraulic loads tested ranged from one to six inches at weekly intervals. The effects of application of the wastewater to the land on crop yields and crop chemical composition were generally favorable for the two hydraulic loads tested, 1 and 2 inches at weekly intervals during the growing season, only, or year-round. Harvested crops removed important amounts of the two key eutropic nutrients, phosphorus and nitrogen. On the forested sites tree growth response was beneficial except with red pine on the Hublersburg soil when 2 inches of wastewater was applied at weekly intervals during the growing season. N and P content of the harvested crops and forest foliage was generally increased by wastewater irrigation.

Nitrate nitrogen levels in water recharging through the soil at the four foot depth were less than 10 mg/l except in the growing-season-2-inch red pine on Hublersburg soil and the year-round-2-inch hardwood area on Morrison sandy loam soil when NO_3-N values were 2 to 4 times the U.S.P.H.S. limit.

Phosphorus concentration in the suction lysimeter water samples at a depth of four feet was no greater on wastewater treated areas than on untreated control areas even on the sandy loam soil. Passage through four feet of soil decreased P concentration 98 to 99% through the combined effects of soil and vegetation in the "living filter" system. Deep well samples adjacent to the Hublersburg soil area showed no changes in water quality from normal background values. One deep well completely surrounded by wastewater treated sandy loam soil showed higher NO_3^- and Cl^- concentrations in the fifth year of treatment but still met U.S.P.H.S. drinking water standards.

Recharge benefit to two nearby University water supply wells was estimated to result in water table build-up equivalent to 2 to 6 feet after a 2 year period of recharge of 6.5×10^7 gallons per year on 43.5 acres.

Annual costs of a spray irrigation system to recycle wastewater through the land was estimated to range from $13 per year per E.D.U. for 1 MGD to $8 per year per E.D.U. for 10MGD.

This report was submitted in fulfillment of Project No. 16080 DYJ under the partial sponsorship of the Water Quality Office, Environmental Protection Agency.

CONTENTS

Section		Page
I	Conclusions	1
II	Recommendations	5
III	Introduction	7
IV	Site Description and Experimental Procedures	11
V	Irrigation System Operation	39
VI	Cropland Aspects	99
VII	Forested Areas	263
VIII	Geohydrology	301
IX	Design and Cost of Spray Irrigation Wastewater Disposal System	383
X	Acknowledgments	415
XI	References	417
XII	Publications	427
XIII	Appendices	431

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FIGURES

Page

1. The Waste Water Renovation and Conservation Cycle 8
2. Location of Waste Water Renovation and Conservation Facilities and Network of Monitoring Wells and Springs 10
3. Flow Diagram Schematic of University Waste Water Treatment Plant 12
4. Water Table Contour Elevations in March, 1963 23
5. Water Table Contour Elevations in April, 1965 24
6. Layout of the Agronomy and Forestry Areas 26
7. Schematic Diagram of Various Types of Monitoring Installations 28
8. Schematic Diagram of Trench Lysimeter 30
9. Oblique View of Trench Lysimeter. Irrigation Lines in the Background Have a Two Percent Grade to Provide Rapid Drainage to Prevent Freezing in the Winter 31
10. Suction Lysimeter Equipment for Sampling Shallow Soil Water (a) and Modified Equipment for Sampling Deep Soil Water (b) 34
11. Monitoring Wells Drilled and Cased Below Streamlines Containing Renovated Sewage Effluent. In Mapview (b) Wells Appear to be Properly Located 36
12. Model I - 2 Inch Rotor Sprinkler (11) 40
13. Model II - 1.5 Inch Rotor Sprinkler (11) 41
14. Indexed Position, Part-Circle Sprinkler, Rainbird Model 35-PJ, Types E and F. (13) 43
15. Random Indexing, Grooved Deflector Sprinkler, Type C. Upper Left View Shows Deflector; Lower Left View Shows Sprinkler Position When Not Operating; Right View Shows Sprinkler in Operating Position. (13) 44

Page

16. Surface Appearance with Various Degrees of Penetration of Snow by Effluent Applied with Different Sprinklers 46

17. Topographic Map of Research Area with Location of Piezometer Sites, Irrigation Lines and V-Notch Weir 48

18. Profile Diagram of Hillside with Location of Piezometer Sites 49

19. Shallow Well Water Level Elevations at Three Sites Showing Typical Responses to Irrigation on 4/17/67 with Two Inches of Sewage Effluent 57

20. Cross Section of Hillside Showing Increase in Elevation of Perched Water Table (cross hatched area) 12 Hours After 2" Irrigation 48

21. Calculation of Water Storing Capacity of the Soil Above the Perched Water Table for Sites 2 and 4 61

22. Water Level Elevations in Piezometers at Site 1 for Two Observation Intervals, 1966-67 64

23. Water Level Elevations in Piezometers at Site 2 for Two Observation Intervals, 1966-67 65

24. Water Level Elevations in Piezometers at Site 3 for Two Observation Intervals, 1966-67 66

25. Water Level Elevations in Piezometers at Site 4 for Two Observation Intervals, 1966-67 67

26. Water Level Elevations in Piezometers at Site 5 for Two Observation Intervals, 1966-67 68

27. Water Level Elevations in Piezometers at Site 6 for Two Observation Intervals, 1966-67 69

28. Water Level Elevations in Piezometers at Site 7 for Two Observation Intervals, 1966-67 70

29. Set of Piezometers at Site 1 Showing Limiting Permeability, Perched Water Table, Water Levels in Piezometers and Predicted Directions of Movement 72

30. Same as Figure 29 but at Sites 2 and 3 73

Page

31. Same as Figure 29 but at Sites 4 and 5 74

32. Same as Figure 29 but at Sites 6 and 7 75

33. Piezometer Water Level Elevations (feet) at Several Sites in 1966 77

34. Runoff Hydrograph for Interval Beginning on May 15, 1967 81

35. Runoff Hydrograph for Interval Beginning on May 23, 1967 82

36. Topographic Map with Seepage Areas Delineated by Shading Two Days After Irrigation 84

37. Irrigation, Precipitation and Interflow Runoff at Various Times After Start of Cycle II, Mar. - Apr., 1967 87

38. Irrigation, Precipitation and Interflow Runoff at Various Times After Start of Cycle III, June - July, 1967 88

39. Piezometer Heads (P/W) vs. Hours After Start of 3-inch Irrigation for All Stations and Depths During Cycle I, Oct., 1966 90

40. Irrigation, Precipitation and Runoff During Cycle III, Feb. - Mar., 1969 92

41. Plan of Strip Cropped Area 101

42. Regression of Removal Efficiency on Nitrogen Loading 144

43. Regression of Removal Efficiency on Phosphorus Loading 145

44. Nitrogen Added in Applied Sewage Effluent and Removed in Harvested Reed Canarygrass and Silage Corn 149

45. Phosphorus Added in Applied Sewage Effluent and Removed in Harvested Reed Canarygrass and Silage Corn 150

46. Diagram of (a) Suction Lysimeter with Single Hole Stopper Assembly and (b) Lysimeter Installed at Depth of 48 Inches with Tubing Inserted to Remove Sample 154

Page

47. Mean Annual Phosphorus Concentration in Suction Lysimeters at the Six Inch Depth in the Corn Rotation Area Receiving 0, 1, and 2 Inches of Wastewater at Weekly Intervals, Apr. - Nov., 1965-1969 157

48. Mean Annual Phosphorus Concentration in Suction Lysimeters at the 24-Inch Depth in the Corn Rotation Area Receiving 0, 1, and 2 Inches of Wastewater at Weekly Intervals, Apr. - Nov., 1965-1969 158

49. Mean Annual Phosphorus Concentration in Suction Lysimeters at the 48-Inch Depth in the Corn Rotation Area Receiving 0, 1, and 2 Inches of Wastewater at Weekly Intervals, Apr. - Nov., 1965-1969 159

50. Nitrate-N in Suction Lysimeters at the 48-Inch Depth in the Corn Rotation and Reed Canarygrass Areas 161

51. Mean Annual Concentration of Various Chemical Constituents in Suction Lysimeter Samples at the 48-Inch Depth in the Reed Canarygrass and Corn Rotation Areas in 1969 165

52. Effect of Various Wastewater Levels on the Corn Rotation Area on Exchangeable Cations Averaged Over Five One-Foot Depth Intervals and Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter for Any Constituent Are Not Significantly Different. P = 0.01 196

53. Exchangeable Magnesium at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01 197

54. Exchangeable Sodium at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01 198

55. Soil pH at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01 200

Page

56. Exchangeable Manganese at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01 201

57. Extractable Chloride at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01 202

58. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 0-12 inches, Plotted According to the Langmuir Equation (8) 223

59. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 12-24 inches, Plotted According to the Langmuir Equation (8) 224

60. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 24-36 inches, Plotted According to the Langmuir Equation (8) 225

61. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 36-48 inches, Plotted According to the Langmuir Equation (8) 226

62. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 48-60 inches, Plotted According to the Langmuir Equation (8) 227

63. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 0-12 inches, Plotted According to the Freundlich Equation (8) 229

64. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 12-24 inches, Plotted According to the Freundlich Equation (8) 230

65. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 24-36 inches, Plotted According to the Freundlich Equation (8) 231

66. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 36-48 inches, Plotted According to the Freundlich Equation (8) 232

67. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 48-60 inches, Plotted According to the Freundlich Equation (8) 233

Page

68. Platinum Microelectrodes and Oxygen Concentration Chambers 254

69. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths in the Hardwood Area on Hublersburg Soil Which Received One Inch of Wastewater at Weekly Intervals. 1965-1969 267

70. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths in the Red Pine Area on Hublersburg Soil Which Received One Inch of Wastewater at Weekly Intervals. 1965-1969 268

71. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths in the Red Pine Area on Hublersburg Soil Which Received Two Inches of Wastewater at Weekly Intervals. 1965-1969 269

72. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths in the Old Field Area on Hublersburg Soil Which Received Two Inches of Wastewater at Weekly Intervals. 1965-1969 270

73. Mean Annual Nitrate-Nitrogen Concentration in Suction Lysimeter Samples at the 48-inch Depth on Various Forest Areas. 1965-1969 280

74. Mean Annual MBAS Concentration in Suction Lysimeter Samples at Three Depths and in the Applied Wastewater in the Hardwood Area on Hublersburg Soil Which Received Four Inches of Wastewater Weekly. 1963-1968 283

75. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths and in the Applied Wastewater in the Hardwood Area on Hublersburg Soil Which Received Four Inches of Wastewater Weekly. 1963-1968 284

76. Mean Annual Nitrate-Nitrogen Concentration in Suction Lysimeter Samples at Three Depths in the Hardwood Area on Hublersburg Soil Which Has Received Four Inches of Wastewater Weekly. 1963-1968 285

77. Percent of UN-14 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values 305

78. Percent of UN-14 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values 307

Page

79. Percent of UN-14 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values 308

80. Percent of UN-14 Deep Well Samples with P Concentrations Equalling or Exceeding Stated Values 309

81. Percent of F-3 Deep Well Samples with P Concentrations Equalling or Exceeding Stated Values 310

82. Percent of F-3 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values 311

83. Percent of F-3 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values 312

84. Percent of F-3 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values 314

85. Percent of F-4 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values 315

86. Percent of F-4 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values 316

87. Percent of F-4 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values 318

88. Percent of F-4 Deep Well Samples with P Concentrations Equalling or Exceeding Stated Values 319

89. Percent of F-5 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values 320

90. Percent of F-5 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values 321

91. Percent of F-5 Deep Well Samples with P Concentrations Equalling or Exceeding Stated Values 322

92. Percent of F-5 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values 323

93. Percent of G-3 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values 332

94. Percent of G-3 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values 333

Page

95. Percent of G-3 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values 335

96. Percent of Deep Trench Lysimeter (SGL) Samples at the Five-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values 337

97. Percent of Deep Trench Lysimeter (SGL) Samples at the Ten-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values 338

98. Percent of Deep Trench Lysimeter (SGL) Samples at the 14-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values 339

99. Percent of Deep Trench Lysimeter (SGL) Samples at the Five-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values 341

100. Percent of Deep Trench Lysimeter (SGL) Samples at the Ten-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values 342

101. Percent of Deep Trench Lysimeter (SGL) Samples at the 14-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values 343

102. Percent of Deep Trench Lysimeter (SGL) Samples at the Five-foot Depth With P Concentrations Equalling or Exceeding Stated Values 344

103. Percent of Deep Trench Lysimeter (SGL) Samples at the Ten-foot Depth With P Concentrations Equalling or Exceeding Stated Values 345

104. Percent of Deep Trench Lysimeter (SGL) Samples at the 14-foot Depth With P Concentrations Equalling or Exceeding Stated Values 346

105. Percent of Deep Trench Lysimeter (SGL) Samples at the Five-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values 348

106. Percent of Deep Trench Lysimeter (SGL) Samples at the Ten-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values 349

Page

107. Percent of Deep Trench Lysimeter (SGL) Samples at the 14-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values 350

108. Percent of Deep Suction Lysimeter (SLG-1) Samples at the Six-foot Depth With P Concentrations Equalling or Exceeding Stated Values 352

109. Percent of Deep Suction Lysimeter (SLG-1) Samples at the 17.5-foot Depth With P Concentrations Equalling or Exceeding Stated Values 353

110. Percent of Deep Suction Lysimeter (SLG-1) Samples at the Six-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values 355

111. Percent of Deep Suction Lysimeter (SLG-1) Samples at the 17.5-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values 356

112. Percent of Deep Suction Lysimeter (SLG-1) Samples at the Six-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values 358

113. Percent of Deep Suction Lysimeter (SLG-1) Samples at the 17.5-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values 359

114. Percent of Deep Suction Lysimeter (SLG-1) Samples at the Six-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values 360

115. Percent of Deep Suction Lysimeter (SLG-1) Samples at the 17.5-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values 361

116. Water Level Declines in Selected Wells 367

117. Rainfall Deficit and Water Level Decline Within the Gatesburg Aquifer Due to Natural Depletion 376

118. Pumping and Non-Pumping Water Levels Related to Decline in Well Yields Within the University Well Field 377

119. Power Requirements for Pumping 1000 Gallons of Water Per Minute at a 100-foot Head for Various Wire to Water Efficiencies (109) 380

Page

120. Land Requirements and Costs with and without a Buffer Zone Related to Daily Flow and Application Rates 390

121. Sprayfield Sprinkler Arrangements 391

122. Required Sprinkler Separation Distances in Relation to Effective Distribution Diameter with Three Types of Spacing 393

123. Number of Sprinklers per Acre in Relation to Effective Distribution Diameter with Three Types of Spacing 394

124. Sprinkler Discharge for Various Effective Distribution Diameters and a 1/4 Inch per Hour Application Rate 396

125. Sprinkler Discharge for Various Effective Distribution Diameters and a 1/6 Inch per Hour Application Rate 397

126. Instantaneous Discharge (gpm/acre) for Various Application Rates 398

127. Required Lengths of Lateral Pipeline for Various Effective Distribution Diameters 399

128. Lateral Flow in Relation to Daily Flow, Application Rate and Side Dimension Ratio of the Irrigation Plot 400

129. Required Lengths of Lateral Pipeline in Relation to Daily Flow, Application Rate and Side Dimension Ratio of the Irrigation Plot 401

130. Lateral or Header Diameters for Various Lateral or Header Flows as Related to Pipe Length and Allowable Headloss 403

131. Headloss for Various Flows and Pipe Diameters 404

132. Capital and Annual Cost Distribution for a 1 MGD Spray Irrigation Wastewater Disposal System 411

133. Annual Cost of Spray Irrigation Wastewater Disposal System per Thousand Gallons for Various Daily Flows 412

134. Annual Cost of Spray Irrigation Wastewater Disposal System per Equivalent Dwelling Unit (EDU) for Various Daily Flows 413

TABLES

No.		Page
1	Composition of Sewage Effluent	14
2	Composition of Applied Effluent Expressed as a Fertilizer Equivalent Formula, N:P:K, at a Rate of 1000 lb per Acre	15
3	Monitored Irrigation Areas and Application System Parameters, 1963-1969	17
4	Summary of Uniformity Coefficients from Rotor Design Tests	42
5	Average Infiltration Rates at Sites 1-7, in Inches per Hour	50
6	Average Percolation Rates (inches per hour) at Six Inch Intervals to Depths Listed at Sites 1-7	50
7	Average Aeration Porosity (Percent by Volume) at 50 cm Water Tension at Six Inch Intervals to Depths Listed at Sites 1-7	51
8	Bulk Density (grams per cc) at Six Inch Intervals to Depths Listed at Sites 1-7	52
9	Percentages of Total Porosity, Porosity from 175 to 10 Microns and from 10 to 0.10 Microns in Diameter for Sites 1-7 at the Given Depth Intervals	53
10	Shallow Well Elevations for Sites 1-7 on April 17-21, 1967	56
11	Time in Hours After Termination of Irrigation for Shallow Well Readings Presented in Table 10	56
12	Water Level Elevations (feet) with Respect to Irrigation and Rainfall at Sites 1-7	59
13	Total Declines in Water Levels of Shallow Wells in Feet and Order of Rapidity of Decline in Water Levels by Sites 1-7	60
14	Aeration Porosity and Water Storage Values (Inches) for Six-Inch Depth Increments in the Soils at Sites 2 and 4	62

No.		Page
15	Soil Permeabilities Determined on July 11, 1967 by the Piezometric Method for All Piezometers at Sites 1-7	63
16	Correlation Coefficients Relating Soil Permeability and Various Soil Properties	63
17	Peak Water Level Elevations for Shallow Wells and Piezometers for the Interval 1/2 - 1/6/67 at Sites 1-7	71
18	Surface Runoff Expressed as Peak Discharge (gpm per acre), Total Discharge (gal./acre), and Percent of the Total Application for the Indicated Dates	78
19	Soil Temperatures Averaged for 7 Sites at Various Depths Before and After Irrigation for Examples A, B, and C	79
20	Effects of Air Temperature and Soil Frost Conditions on Surface Runoff for Three Irrigation Applications	80
21	Total Duration of Runoff from 2-Inch Irrigation and Duration After Termination of Irrigation	80
22	Phosphorus Content in Applied Effluent, in a 6 In. Suction Lysimeter, and in Total Runoff at Different Times Expressed as Hours After Irrigation Had Terminated	83
23	Percentage of Irrigation Amount Appearing as Runoff (R/I) and Inches of Total Precipitation which Occurred During the Week Prior to Irrigation for all Cycles	86
24	Average Peak Pressure Heads in Piezometers for the Six Runs and the Three Cycles	89
25	Sequences, Areas Irrigated and Dates of Each Irrigation Cycle	93
26	Percentage of Effluent Volume Applied Appearing as Runoff during the Minimum and Maximum Sequences for Five Irrigation Cycles	94
27	Peak Runoff Rates Relative to Irrigation Application Rates during the Minimum and Maximum Sequences for the Five Irrigation Cycles	94
28	Maximum Air Temperatures and Peak Rates of Runoff Relative to Irrigation Application Rates for Cycles II and III	95

No.		Page
29	Concentrations in Parts Per Million of Phosphorus and Nitrogen and Percent Change in Concentration in Watershed Runoff at Four Sampling Times for Four Irrigation Cycles	96
30	Crop Rotation Sequence	102
31	Irrigation Program for Agronomy Areas	103
32	Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1963	105
33	Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1964	106
34	Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1965	107
35	Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1966	108
36	Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1967	109
37	Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1969	110
38	Yields of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1965-1969	111
39	Normal Monthly Precipitation and Deviations from the Normal - Inches	111
40	Average Nutrient Composition of Red Clover Hay Receiving Various Levels of Sewage Effluent Per Week. 1963-1964	112
41	Average Nutrient Composition of Alfalfa Hay Receiving Various Levels of Sewage Effluent Per Week, 1963, 1965-1967	113
42	Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1963	114
43	Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1964	115

No.		Page
44	Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1965	116
45	Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1966	117
46	Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1967	118
47	Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1969	119
48	Average Nutrient Composition of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week. 1965-1969	120
49	Quantities of Nutrients (Pounds Per Acre) Removed by Red Clover Receiving Various Levels of Sewage Effluent Per Week. 1965-1964	122
50	Quantities of Nutrients (Pounds Per Acre) Removed by Alfalfa Receiving Various Levels of Sewage Effluent Per Week. 1963, 1965-1967	123
51	Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1963	124
52	Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1964	125
53	Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1965	126
54	Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1966	127
55	Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1967	128
56	Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1969	129

No. Page

57 Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week. 1965-1969 130

58 Average Concentration (mg/l) of Various Constituents in Wastewater Applied to the Rotation Crops at Rates of One and Two Inches Per Week - 1963-1969 131

59 Average Concentration (mg/l) of Various Constituents Applied to the Reed Canarygrass Area - 1965-1969 133

60 Total Amounts (Pounds Per Acre) of Various Constituents in Sewage Effluent Applied to the Rotation Crops at Rates of One and Two Inches Per Week - 1963-1969 134

61 Total Amounts (Pounds Per Acre) of Various Constituents Applied to Reed Canarygrass Receiving Two Inches of Sewage Effluent Weekly - 1965-1969 136

62 Renovation Efficiency (Percent) of Crops at One and Two Inch Per Week Applications - 1963 137

63 Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Applications - 1964 138

64 Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Applications - 1965 139

65 Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Applications - 1966 140

66 Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Applications - 1967 141

67 Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Applications - 1969 142

68 Renovation Efficiency (Percent) of Reed Canarygrass at Two Inches of Sewage Effluent Application - 1965-1969 143

69 Average Removal Efficiencies of Various Crops of Nitrogen and Phosphorus in Comparable Years 146

70 Amounts Removed in Harvested Crops Per Acre Per Crop Year on Wastewater Treated Areas - 1963-1969 147

No.		Page
71	Mean Annual Concentration (mg/l) of Phosphorus in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	166
72	Mean Annual Concentration (mg/l) of Nitrate Nitrogen in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	167
73	Mean Annual Concentration (mg/l) of Kjeldahl Nitrogen in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	168
74	Mean Annual Concentration (mg/l) of Ammonium Nitrogen in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1968-1969	169
75	Mean Annual Concentration (mg/l) of Potassium in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	170
76	Mean Annual Concentration (mg/l) of Calcium in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	171
77	Mean Annual Concentration (mg/l) of Magnesium in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	172
78	Mean Annual Concentration (mg/l) of Sodium in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	173
79	Mean Annual Concentration (mg/l) of Chloride in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	174
80	Mean Annual Concentration (mg/l) of Manganese in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	175

No.		Page
81	Mean Annual Concentration (mg/l) of Boron in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	176
82	Mean Annual pH in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	177
83	Mean Annual Concentration (mg/l) of MBAS in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969	178
84	Mean Annual Concentration (mg/l) of Various Constituents in Suction Lysimeter Samples at Three Depths in the Reed Canarygrass Area Receiving Two Inches of Wastewater Weekly. 1966-1969	179
85	The Effect of Years on Mean Annual Concentration (mg/l) of Phosphorus in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	180
86	The Effect of Years on Mean Annual Concentration (mg/l) of Nitrate Nitrogen in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	181
87	The Effect of Years on Mean Annual Concentration (mg/l) of Kjeldahl Nitrogen in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	182
88	The Effect of Years of Mean Annual Concentration (mg/l) of Ammonium Nitrogen in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1968-1969	183
89	The Effect of Years on Mean Annual Concentration (mg/l) of Potassium in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	184
90	The Effect of Years on Mean Annual Concentration (mg/l) of Calcium in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	185

No.		Page
91	The Effect of Years on Mean Annual Concentration (mg/1) of Magnesium in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	186
92	The Effect of Years on Mean Annual Concentration (mg/1) of Sodium in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	187
93	The Effect of Years on Mean Annual Concentration (mg/1) of Chloride in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	188
94	The Effect of Years on Mean Annual Concentration (mg/1) of Manganese in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	189
95	The Effect of Years on Mean Annual Concentration (mg/1) of Boron in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	190
96	The Effect of Years on Mean Annual pH in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	191
97	The Effect of Years on Mean Annual Concentration (mg/1) of MBAS in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969	192
98	Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1963	205
99	Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1965	206
100	Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1966	207

No. Page

101 Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1967 208

102 Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1968 209

103 Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1969 210

104 Chemical Characteristics of Soil Samples at Five Depths from the Reed Canarygrass Area Which Received Two Inches of Wastewater Per Week. 1969 211

105 Chemical Characteristics of Soil Samples at Five Depths from Plots of the Hardwood Area on Morrison Sandy Loam Soil at the Gamelands Which Received 0 and 2 Inches of Wastewater Weekly. 1967 212

106 Chloride Content of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater 213

107 Boron Content of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 214

108 Nitrogen and Organic Matter Content of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater 215

109 Physical and Chemical Characteristics of Soil Samples from Control Plots of the Corn Rotation Area 220

110 Equilibrium Concentration (mmole/ℓ) and Phosphorus Adsorbed (mg/g) by Untreated Soil from Various Depths 221

111 Equilibrium Concentration (mmole/ℓ) and Phosphorus Adsorbed (mg/g) by Treated Soil from Various Depths 222

112 Phosphorus Langmuir Adsorption Maxima (µg/g) of Untreated and Treated Soil in Relation to Depth 228

113 Phosphorus Adsorbed in an Equilibrium Concentration of 100 mg P/1 as Determined from the Freundlich Adsorption Isotherms 234

No.		Page
114	Bray Phosphorus (μg/g) in Soil Samples Obtained in Different Years at Five Depths from Plots Receiving Various Levels of Wastewater Applications	235
115	Mean Yield and Boron Content of Beans Grown in Field Plots Receiving Various Levels of Wastewater. 1967	239
116	Average Concentration of Boron (mg/l) in Lysimeter Samples During Irrigation (adsorption) and Non-Irrigation (desorption) Periods, 1967-1968	239
117	Average Plant Weights and Chemical Composition of Bean Plants from Greenhouse Experiment--Control Area Soil	242
118	Average Plant Weights and Chemical Composition of Bean Plants from Greenhouse Experiment--One Inch Area Soil	243
119	Average Plant Weights and Chemical Composition of Bean Plants from Greenhouse Experiment--Two Inch Area Soil	244
120	Effect of Boron Treatment and Source of Soil on Dry Weight (grams) of Bean Plants in Greenhouse Experiment	245
121	pH and Water Soluble Manganese Content of Soil from Pots Used in Greenhouse Study	246
122	Effect of Boron Treatment and Source of Soil on Boron Content (μg/g) of Bean Plants in Greenhouse Experiment	247
123	Autoclave-Extractable Boron Content of Soil Materials Used in Greenhouse Experiment--μg/g	248
124	Boron Adsorbed by the Soil Materials Equilibrated with the 5.0 mg/l Solution	249
125	Dithionate-Citrate Extractable Fe_2O_3 and Boron Adsorptive Capacity of the Nine Soil Materials from the Three Wastewater Treatments	250
126	Ranked Means in Ascending Order of the Main Factors of Oxygen Diffusion Rate Experiment	257
127	Ranked Means of the Main Factors of the Oxygen Concentration Experiment	258
128	Concentration of Various Forms of Nitrogen and of Manganese and Iron in Soil Water Samples	259

No. Page

129 The Crop x Effluent Interaction with Respect to Nitrate Nitrogen Levels in Suction Lysimeter Samples Averaged Over Both Depths 260

130 Chemical Composition of Sewage Effluent Applied on the Experimental Plots (Farm Woodlot Site) During the Period April 15, 1969 to October 29, 1969 264

131 Average Concentration of Constituents in the Percolate Water Samples Collected from Tension Lysimeters in the Effluent Treated Plots at the Farm Woodlot Site During the Irrigation Period April 15 to October 29, 1969 265

132 Average Concentration of Constituents in the Percolate Water Samples Collected from Tension Lysimeters in the Control Plots at the Farm Woodlot Site During the Period April 15 to October 29, 1969 272

133 Average Concentration of Percolate Samples Collected from Forest Floor Pans and Tension Lysimeters in the New Red Pine 2" Per Week Area During the Irrigation Period 4-15-69 to 10-29-29 274

134 Average Concentration in Percolate Samples Collected from Forest Floor Pans and Tension Lysimeters in the New Gamelands Area Which Received 2" of Effluent Per Week During the Period 1-1-69 to 12-31-69 276

135 Average Concentration in Percolate Samples Collected from Forest Floor Pans and Tension Lysimeters in the Control Plot at the New Gamelands Site During the Period 1-1-69 to 12-31-69 277

136 Mean Annual Concentration (mg/1) of Nitrate-Nitrogen in Suction Lysimeter Samples at Three Depths in Forest Areas Receiving Various Levels of Wastewater. 1965-1969 278

137 Average Concentration of Constituents in the Applied Sewage Effluent and in the Percolate Water Samples Collected from Pan Lysimeters Located in the Hardwood Plot Which Received 4 Inches of Effluent Per Week During the Period April 15 to October 14, 1968 281

138 Mean Concentration of Chemical Elements in the Soil Samples Collected in 1963, 1964, and 1965 in the Hardwood 1-Inch Treatment and Control Plots 287

No.		Page
139	Mean Concentration of Chemical Elements in the Soil Samples Collected in 1965 in the Hardwood 4-Inch Treated Plot	289
140	Average Chemical Content of Tree Foliage and Old Field Ground Vegetation at the End of the 1965 Irrigation Season	291
141	Average Chemical Content of Tree Foliage and Old Field Ground Vegetation at the End of the 1966 Irrigation Season	292
142	Average Chemical Content of Tree Foliage and Old Field Ground Vegetation at the End of the 1967 Irrigation Season	293
143	Average Annual Diameter Growth for Period 1964 to 1969	295
144	Average Annual Terminal Height Growth in the Red Pine Plots During the Period 1963 to 1968	296
145	Average Annual Height Growth of White Spruce	296
146	Growth Response of Ground Vegetation in the Open White Spruce Plots, Expressed in Terms of Dry Matter Production	297
147	Survival of Planted Tree Seedlings - 1965-1969	298
148	Average Total Height Growth of Surviving Seedlings in the First Year, 1965, and in 1969	299
149	Phosphorus in Monitoring Wells	326
150	Nitrate-N in Monitoring Wells	327
151	Chloride in Monitoring Wells	328
152	Chloride Concentrations Equalled or Exceeded by 20%, 50%, and 80% of the Values for 5, 10, and 14 foot Depths in the Gameland's Trench Lysimeter (SGL)	336
153	Nitrate-Nitrogen Concentrations Equalled or Exceeded by 20%, 50%, and 80% of the Values for 5, 10, and 14-foot Depths in the Gameland's Trench Lysimeter (SGL)	340

No. Page

154 Phosphorus Concentrations Equalled or Exceeded by 20% 50%, and 80% of the Values for 5, 10, and 14 foot Depths in the Gameland's Trench Lysimeter (SGL) 347

155 ABS Concentrations Equalled or Exceeded by 20%, 50% and 80% of the Values for 5, 10, and 14 foot Depths in the Gameland's Trench Lysimeter (SGL). 351

156 Phosphorus Concentrations Equalled or Exceeded by 20%, 50% and 80%, of the Values for 6-, 10.4-, 17.5- and 20.3-foot Lysimeters (SLG-1) 351

157 ABS Concentrations Equalled or Exceeded by 20%, 50% and 80% of the Values for 6-, 10.4-, 17.5- and 20.3-foot Lysimeters (SLG-1) 354

158 Chloride Concentrations Equalled or Exceeded by 20%, 50% and 80% of the Values for 6-, 10.4-, 17.5-, and 20.3-foot Lysimeters (SLG-1) 357

159 Nitrate-Nitrogen Concentrations Equalled or Exceeded by 20%, 50% and 80% of the Values for 6-, 10.4-, 17.5-, and 20.3-foot Lysimeters (SLG-1) 357

160 Nitrate-Nitrogen Concentrations Equalled or Exceeded by 20%, 50% and 80% of the Values for a Suction Lysimeter, SLK-1, in a Cropland1/ Area at the Gamelands Which Received Two Inches of Effluent Per Week, Year-Round, Since July, 1965 362

161 Estimates of Recharge to the Groundwater Reservoir on Each Acre Receiving Two Inches of Effluent Per Week 366

162 Selected Values for Coefficients of Transmissivity and Storage Obtained from Pumping Tests Conducted in the University Well Field (Modified from S. H. Siddiqui, 1969) (101) 370

163 Relation Between Aquifer Hydraulic Properties and Water Table Buildup for Two University Water Supply Wells 374

164 Effluent Storage Needs 405

165 Costs of a Land Disposal System for Treated Municipal Wastewater (1967 dollars) 408

SECTION I

CONCLUSIONS

1. Application of secondary treated municipal wastewater to cropland at levels of one or two inches at weekly intervals results in a guaranteed economic level of crop yield while at the same time recharging 60 to 100% of the applied wastewater as potable water on a well-drained, silt loam or clay loam soil.

2. Application of secondary treated municipal wastewater to forest areas at a level of one inch at weekly intervals on a well-drained silt loam or clay loam soil results in improved diameter growth of the trees and recharge of 60 to 100% of the applied wastewater as potable water.

3. Application of secondary treated municipal wastewater to forest areas at a level of two inches at weekly intervals during the growing season varied in its effects depending on soil and vegetative cover type. On the Hublersburg silt loam or clay loam soil red pine growth was adversely affected but white spruce height and diameter growth was more than doubled. On the red pine area, with no ground vegetation, nitrate-nitrogen concentration in the soil water at a depth of four feet exceeded the U.S.P.H.S. recommended value for potable water but on the white spruce area, with a lush ground vegetation, nitrate-nitrogen remained well below the U.S.P.H.S. value of 10 mg NO_3-N per liter. On the other hand, year-round irrigation on a well-drained Morrison sandy loam soil, with mixed hardwood cover, diameter growth was doubled but nitrate-nitrogen levels at a depth of four feet greatly exceeded 10 mg NO_3-N per liter.

4. After four years, application of four inches of wastewater per week as a split application of two inches each on Monday and Thursday on a silt loam soil with a mature hardwood cover resulted in nitrate concentrations in the soil water which were well below the U.S.P.H.S. drinking water limit and phosphorus concentrations which were no greater than on the control.

5. Crop removal contributes substantially to renovation of the wastewater by removing the equivalent of 20 to 80% of the applied phosphorus and 40 to over 100% of the applied nitrogen. Absolute amounts of P removed ranged from 10 to 59 lb/acre and that of nitrogen ranged from 36 to 356 lb/acre.

6. Phosphorus not used by the crop over a 7-year period has been retained in the upper foot of the Hublersburg clay loam soil and in the upper two feet of the Morrison sandy loam soil. Phosphorus concentration in the soil water at the four foot depth has remained the same on both the wastewater-treated and control areas.

7. Chemical water quality changes in deep (160 to 300 feet) monitoring wells, on-site, have been non-significant at the cropland and forest areas with the Hublersburg soils but significant increases in nitrate and chloride occurred in one well on the forested Morrison sandy loam area. The concentrations, however, have remained well below the U.S. P.H.S. drinking water limits for these constituents and all other recommended drinking water limits.

8. Chemical composition of harvested crops treated with wastewater were well within the normal range of such crops as reported in agronomic literature. Effluent treated hay crops were generally higher in content of phosphorus, nitrogen, potassium, magnesium, chloride, and sodium than fertilized but unirrigated crops. The same was true for the corn crops except for nitrogen, in which case the effluent treatment effect was about equally positive and negative.

9. The principal soil chemical changes induced in the Hublersburg soil by wastewater treatment were: 1. a substantial increase in Bray extractable phosphorus in the upper foot of soil; 2. a large relative increase but small absolute increase in exchangeable sodium in at least the upper five feet of soil; 3. a substantial increase in exchangeable magnesium to a depth of five feet; 4. a significant but small absolute increase in exchangeable manganese in the third, fourth and fifth foot; and 5. a significant and large increase in NH_4NO_3-extractable chloride in at least the upper five feet of soil.

10. Boron concentration in the wastewater and transit through the soil does not constitute any immediate or future hazard to crop or forest growth, or to the groundwater.

11. Hydraulic loads of two inches of wastewater at weekly intervals year-round, caused no surface runoff on the forested Morrison sandy loam site or on the forested or corn rotation Hublersburg clay loam soil site irrigated from April to November. The same hydraulic load on a grassed Hublersburg clay loam soil resulted in up to 100% surface runoff when the soil was frozen and covered with ice.

12. On sloping areas with slowly permeable subsoils hydraulic loads of two inches at weekly intervals can result in a perched water table, downslope interflow and seepage to the surface at breaks in the slope. Phosphorus and nitrogen content of the water is substantially decreased in such flows.

13. Programming the hydraulic load of one or two inches at weekly intervals maintained an aerobic condition in the upper root zone of the Hublersburg clay loam soil on the corn rotation area. The transient perched water table on the 2-inch reed canarygrass area is probably contributing substantially to the nitrate removal capacity of this area by inducing denitrification.

14. Irrigation equipment available on the commercial market is adequate for year round operation under central Pennsylvania weather conditions in either cropland or forested areas.

15. Estimated annual costs for a spray irrigation system containing: a pumping station, a storage lagoon with a capacity equal to forty times the average daily flow, land costs of $140 per acre, a two-inch per week wastewater load, a one-mile force main with a 200 foot elevation lift, a solid set aluminum piping irrigation system with 98 foot lateral spacing and 70-foot sprinkler spacing with 3-foot risers, labor and power costs, amortization of capital costs over a 20-year period at 6% interest, engineering and contingencies at 10% of capital costs were: 1MGD - $46,570, 5MGD - $146,800, 10MGD - $263,060.

16. Estimated annual cost per equivalent dwelling unit (3.5 persons at 100 gallons per capita per day) with the parameters cited in item 15 range from $13.00 per year for a 1MGD system to $8.00 per year for a 10MGD system.

SECTION II

RECOMMENDATIONS

1. These studies were carried on at well-drained soil sites. Similar studies should be made on moderately well to poorly drained soils to evaluate their inherently greater denitrification potential.

2. The feasibility of wastewater treatment by the land has been established. Studies should be conducted on whether the same pipeline and irrigation system can be utilized for land treatment of the sewage plant digested sludge, thereby decreasing the total sewage treatment cost. Studies initiated in 1971 look very promising.

3. The effects of wastewater application on other segments of the total ecologic system on the landscape need to be investigated notably the game animals, songbirds, insects, etc. With the University about to install a 4MGD land treatment system in 1974 approximately 500 acres would become available for such studies.

4. Further studies need to be made on how the hydraulic loading might be varied to stimulate greater removal of nitrogen by denitrification within the soil profile.

5. Further investigations would be desirable on the utility of treated municipal wastewater and/or sludge on sites with high value forest products such as Christmas trees, ornamentals, nursery seedlings and high population density - three to five year rotation pulpwood.

6. An in depth study is needed on the economic evaluation of a wastewater recycling site in terms of the total water resources of an area, particularly in the development of a plan for the management of the water resources of a municipality.

7. Human health aspects of a spray irrigation wastewater recycling system need to be evaluated with respect to:

   a. The dispersion of pathogens, especially viruses in aerosols derived from spray irrigation.

   b. The survival of enteric pathogens in the soil and on vegetation and the probability of hazard to livestock and humans.

8. Heavy metal data obtained in this study was confined to assays for copper and zinc in a few forest foliage samples. Although the heavy metal concentrations in the wastewater have been low further studies would be desirable on the fate of these metals in the soil and their probable future effect on plant growth and food chain aspects and on soil micro- and macro-flora and fauna.

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9. Although two satellite studies have been completed on the effects of wastewater application on wood quality, additional studies with other species are needed.

10. In the present study there have been indications of changes in dominance of certain species in the understory of wastewater treated hardwood stands. The long term implications of this for the ecosystem stability of a forest plant community and forest tree reproduction should be studied.

SECTION III

INTRODUCTION

Dilution of wastewater in streams and lakes is no longer satisfactory in part because many wastes alter the balance of life in the stream or lake and in part because the abundance of nutrients in the wastes causes excessive growth of aquatic weeds which detracts from the aesthetic and recreational value of the body of water.

The need to find methods for disposal of wastes other than by emptying them into streams, lakes, and oceans, the desire to conserve the nutrients by growing useful vegetation rather than aquatic weeds and the urgency of replenishing the groundwater supply by recharge of the renovated waste water led to a consideration of the feasibility of a terrestrial means of disposal.

The problem in State College, Pennsylvania, was the degradation of Spring Creek which resulted from the enrichment of the stream by the nutrients in the effluent from the sewage treatment plant. As a result, portions of the stream became choked with vegetation. For this reason a study was initiated at The Pennsylvania State University to determine: (1) the feasibility of the year-round disposal of sewage effluent on land; (2) the degree of renovation of sewage effluent by means of biological chemical and mechanical processes in soils; (3) the extent of conservation of water by returning it to the groundwater supply; and (4) the effects of the application of effluent on soils crops, trees, and wildlife. The attack on the problem was initiated by assembling an inter-disciplinary team of research personnel including agricultural and civil engineers, agronomists, biochemists, foresters, geologists, microbiologists, and zoologists. After defining the problem and reviewing alternative solutions, plans and procedures were developed with the advice and counsel of representatives of the Pennsylvania Department of Health. The plans called for testing a system for spraying sewage effluent on croplands and forested areas to establish a cycle of renovation (Fig. 1) which would use and purify waste water and return most of it to the underground reservoir. Preliminary studies of potential disposal sites indicated that areas were available on University farm and forest land and contiguous state game-lands. More intensive geological studies indicated that soil mantle thickness, character of the bedrock, and depth to the permanent water table were satisfactory. A monitoring network was established within a 10-mile radius of the proposed project sites and consisted of approximately 50 private and public wells, six springs and one stream. Beginning in April 1962, for one year prior to application of any effluent, water samples were collected from this network and chemically and bacteriologically analyzed (Fig. 2).

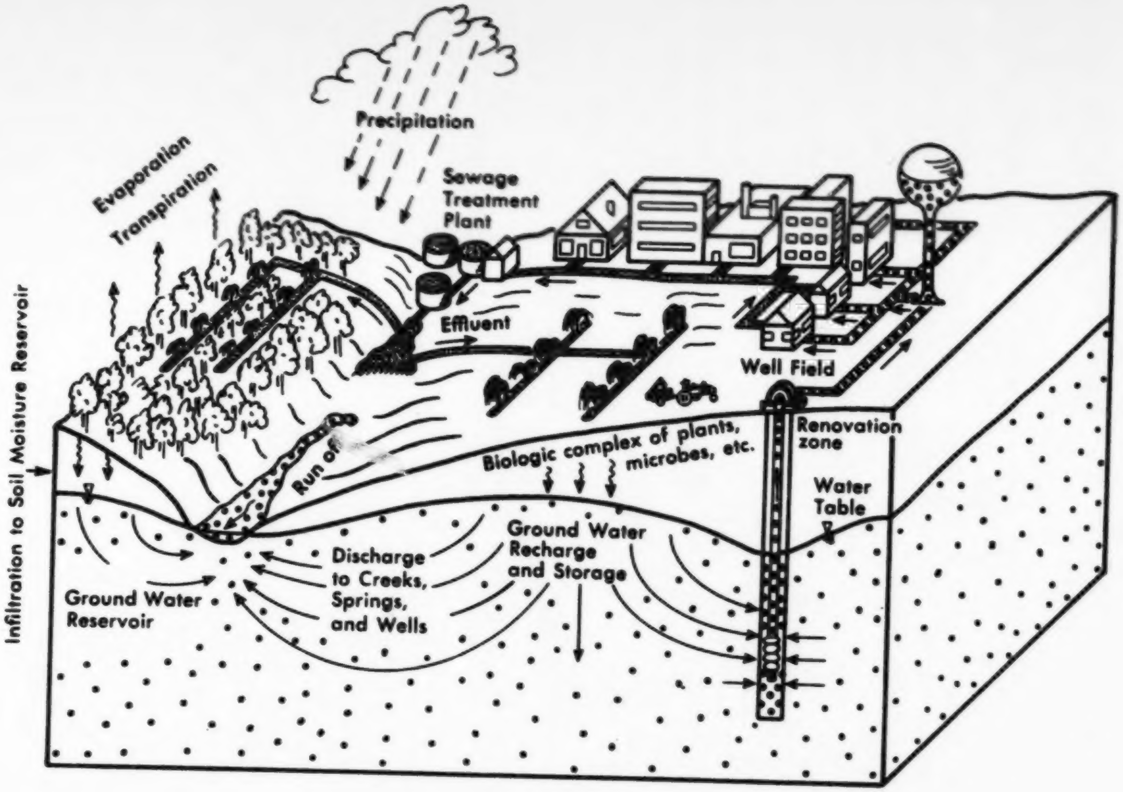

Precipitation
Evaporation
Transpiration
Sewage Treatment Plant
Effluent
Well Field
Renovation zone
Biologic complex of plants, microbes, etc.
Run off
Water Table
Infiltration to Soil Moisture Reservoir
Ground Water Recharge and Storage
Discharge to Creeks, Springs, and Wells
Ground Water Reservoir

FIGURE 1. The Waste Water Renovation and Conservation Cycle

On November 1, 1962, the Sanitary Water Board issued a permit to the University authorizing the disposal of effluent by spray irrigation on certain terrestrial sites under specified conditions. The pumping plant, pipeline, and irrigation systems were designed and installed and the first effluent applied by May 16, 1963 (Fig. 2).

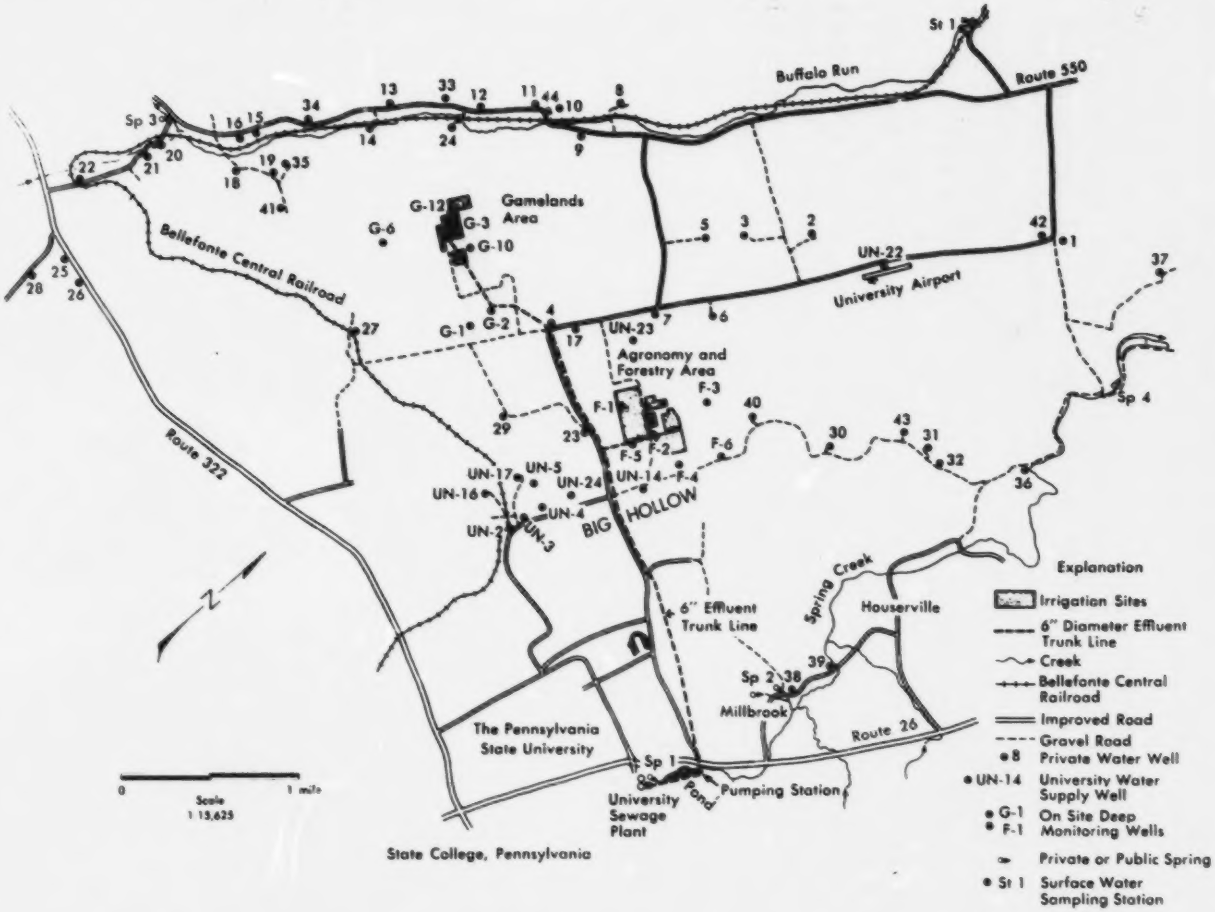
The University financed the studies for the first three years through State and Hatch funds. This continuing support was supplemented on May 1, 1965, by a Water Supply and Pollution Control Demonstration Project Grant (WPD 95-01-65) from the Public Health Service of the U. S. Department of Health, Education and Welfare and subsequent grants, WPD 95-02, 03 and 04 of successor agencies, FWPCA and FWQA, U.S.D.I. and E.P.A., and an O.W.R.R.-U.S.D.I. matching grant.

Detailed descriptions of the geology, hydrology, vegetation, soils, monitoring systems and preliminary results to 1965 were reported in Penn State Studies No. 23 (1) and interim reports on various segments of the study have been published as journal articles and conference proceedings and have been the subject of approximately twenty graduate theses. A listing of these publications is given in the Appendix.

Coordination of the project was under the direction of Dr. Michael A. Farrell, Director of the Agricultural Experiment Station, until 1968 and subsequently under Dr. Louis T. Kardos, Environmental Scientist, in the Institute for Research on Land and Water Resources.

The principal objectives of the project were:

1. To determine to what extent the biological complex of forest, crops and soil is capable of preparing sewage effluent for recharge and reuse.
2. To determine criteria for selecting non-aqueous sites for safe disposal of sewage effluent.
3. To develop and apply to the data gathered under Objectives 1 and 2 a systems analysis procedure for the determination of minimum net costs for land disposal systems in terms of municipal sewer service charges.


St 1
Buffalo Run
Route 550
Sp 3
16
15
34
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35
41
G-12
Gamelands Area
G-3
G-6
G-10
5
3
2
42
1
UN-22
University Airport
37
Bellefonte Central Railroad
28
25
26
27
G-1
G-2
4
17
UN-23
7
6
Agronomy and Forestry Area
F-3
F-1
F-2
F-5
F-6
40
30
43
31
32
Sp 4
36
29
23
Route 322
UN-17
UN-5
UN-24
UN-14
F-4
UN-16
UN-4
BIG HOLLOW
UN-2
UN-3
N
6" Effluent Trunk Line
Spring Creek
Houserville
Sp 2
38
39
Millbrook
Route 26
The Pennsylvania State University
Sp 1
University Sewage Plant
Pond
Pumping Station
State College, Pennsylvania
0
1 mile
Scale
1 13,625
Explanation
Irrigation Sites
6" Diameter Effluent Trunk Line
Creek
Bellefonte Central Railroad
Improved Road
Gravel Road
8 Private Water Well
UN-14 University Water Supply Well
G-1 F-1 On Site Deep Monitoring Wells
Private or Public Spring
St 1 Surface Water Sampling Station

Figure 2. Location of Waste Water Renovation and Conservation Facilities and Network of Monitoring Wells and Springs.

SECTION IV

SITE DESCRIPTION AND EXPERIMENTAL PROCEDURES

SEWAGE TREATMENT PLANT AND WASTEWATER QUALITY

The effluent applied at the irrigation sites is wastewater from The Pennsylvania State University and the Borough of State College, Pa., which has been completely treated in a wastewater treatment plant owned and operated by the University. The plant serves a total of 13,000 permanent residents and another 20,000 students at the University most of the time. It also serves the entire University with its diversity of wastes.

The present wastewater treatment facility shown in Figure 3 is actually two parallel, two-stage treatment plants each having a design capacity of approximately two million gallons per day (mgd). One plant treats University sewage and excess flow from the half of the plant treating Borough wastewater. It contains primary treatment units consisting of a barminutor, pre-aeration (1.90 hours, detention times based on average flow), and primary settling (3.63 hours). The first stage of secondary treatment is provided by two high rate (76-foot diameter by 6-foot stone depth) trickling filters while the second stage consists of a modified activated-sludge process (2.25 hours) followed by final settling tanks (2.81 hours).

The parallel plant treats a portion of the Borough sewage. The primary treatment units in this plant are a barminutor and a grit chamber. Secondary treatment is a two-stage, modified activated-sludge process carried out in two oxidators of the Halmur type operating in series. Each oxidator has a central circular aeration chamber (1.25 hours) surrounded by a concentric settling tank (2.86 hours). Excess activated sludge is concentrated in a flotation thickener before it is digested. A single, separate sludge-digestion facility serves both plants. It contains two heated sludge digesters, the primary unit having a floating cover and Perth gas recirculation system and the secondary unit a floating gas holder. Each unit is 50 feet in diameter with an 18-foot side-water depth and 4-foot-deep conical bottom. Supernatant liquor can be aerated and returned to the influent end of the plant treating University sewage but usually it and the digested sludge are pumped into a tank truck and distributed on hay and pastureland.

Disinfection of the combined final effluent from both plants is accomplished in two chlorine contact tanks with a contact time of 14.2 minutes at a maximum design flow of 15 mgd. Present contact time averages about 35 minutes. Chlorination is controlled to give a residual chlorine of at least 0.5 mg/1. The effluent from these tanks may be discharged into a small pond known as the Duck Pond or into a

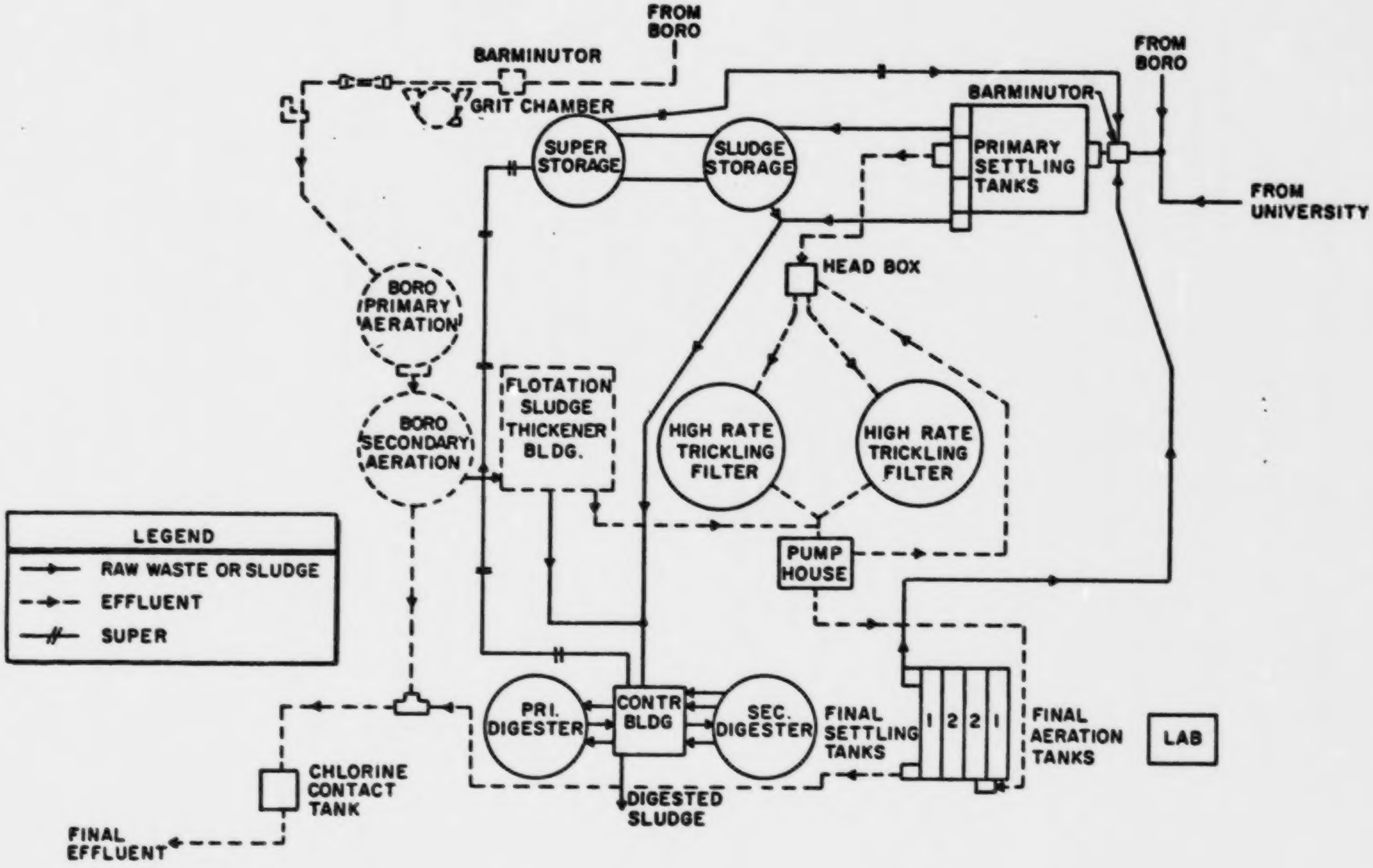

FROM BORO
BARMINUTOR
GRIT CHAMBER
FROM BORO
BARMINUTOR
SUPER STORAGE
SLUDGE STORAGE
PRIMARY SETTLING TANKS
FROM UNIVERSITY
HEAD BOX
BORO PRIMARY AERATION
BORO SECONDARY AERATION
FLOTATION SLUDGE THICKENER BLDG.
HIGH RATE TRICKLING FILTER
HIGH RATE TRICKLING FILTER
PUMP HOUSE
LEGEND
RAW WASTE OR SLUDGE
EFFLUENT
SUPER
PRI. DIGESTER
CONTR BLDG
SEC. DIGESTER
FINAL SETTLING TANKS
1
2
2
1
FINAL AERATION TANKS
LAB
CHLORINE CONTACT TANK
DIGESTED SLUDGE
FINAL EFFLUENT

Figure 3. Flow Diagram Schematic of University Waste Water Treatment Plant.

24-inch pipeline that by-passes the pond. Although this effluent does not have the quality of drinking water, it is relatively clear and odorless and would not cause any physical nuisances. A typical example of the physical and chemical composition of the effluent is shown in Table 1.

The quality of the wastewater applied to the various experimental areas is given in greater detail in later sections. The fertilizer equivalent value of the wastewater applied to the Agronomic Area is given in Table 2. The average cost to a farmer in purchasing the major fertilizer nutrients applied per acre annually with the two-inch per week additions from Apr to Nov would be about $50. Or expressed in other terms each inch of wastewater applied per acre has a fertilizer value worth approximately $.85. This represents a substantial contribution to any spray disposal area which would be used for food, feed or fiber production.

Microbiological assays of the wastewater as it arrived at the disposal site (2) showed an average total coliform density of 578 per 100 ml in 26 samples over the period 7/8/65 - 4/22/66. This value is below the recommended limits for recreation use other than primary contact. If the fecal coliforms were to constitute less than 40% of the total coliforms (a highly probable case), the wastewater would also meet the recommended limits for primary contact recreation water.

In a virus isolation study conducted by Dr. Ernest H. Ludwig, Prof. of Microbiology, 30 "sewer swab" samples of the chlorinated wastewater were obtained during a nine week period, Aug 16 - Oct 17, 1967. One half of the samples were obtained at the outflow of the chlorine detention tank at the sewage treatment plant. The other 15 samples were obtained from a four-inch irrigation main 2½ miles from the sewage plant at the Agronomy Area. Water from the supply line was allowed to flow through a 240 gallon tank at a rate of 2.0 gallons per minute. Sampling at each location was accomplished by suspending a 4 inch x 4 inch cotton gauze "sewer swab" in the flow for 3 or 4 days. In this manner sampling of the wastewater was continuous for the nine-week period. Each pair of samples from the two sampling positions had an equal exposure period. Cultures of rhesus monkey kidney cells and human amnion cells were each innoculated in duplicate with isolates from the "sewer swabs" and all samples were passed to a second set of fresh cell cultures at least one time. Additional passages were made when deemed necessary.

With these procedures no virus isolated from any of the samples from the irrigation line at the field site. One agent isolated from the sample representing the period, Sept 22-25, at the outflow from the sewage treatment plant. These data indicate that the probability of viral contamination in a reasonably sanitized wastewater is very small

Table 1. Composition of Sewage Effluent

Substance	Concentration - mg/l Aug, '69 - Aug, '70[a]	 1968-70[b]
Turbidity (Jackson Units)	12	
Residue		
Total	360	
Fixed	220	
Suspended Residue		
Total	25	
Fixed	3	
Biochemical Oxygen Demand (BOD)	15	
Alkalinity as $CaCo_3$	140	
Sulfate as SO_4	40	
Aluminum	0.15	
Organic - N		4.9
Ammonia - N		11.0
Nitrate - N		5.1
Apparent ABS (MBAS)		0.5
Orthophosphate as P		5.3
Potassium		15.0
Calcium		27.0
Magnesium		13.5
Sodium		41.6
Chloride		48.3

[a] Analyzed in Sanitary Engineering Lab.

[b] Analyzed in Agronomy Department Lab. Average of 104 weekly composite samples obtained during irrigation of Agronomy Areas.

Table 2. Composition of Applied Effluent Expressed as a Fertilizer Equivalent Formula, N:P:K, at a Rate of 1000 lb per Acre

Year	Fertilizer Equivalent Formula (N-P-K) 1 Inch per Week	 2 Inches per Week
1963	7 - 5 - 9	14 - 10 - 18
1964	14 - 6 - 12	25 - 13 - 23
1965	6 - 4 - 13	11 - 9 - 27
1966	10 - 4 - 15	18 - 8 - 28
1967	5 - 3 - 10	11 - 8 - 21
1968	9 - 2 - 8	20 - 6 - 15
1969	9 - 2 - 5	16 - 5 - 10

and of no concern, particularly in as much as the soil filtration which would occur provides an additional very effective safety factor.

PUMPING PLANT AND WASTEWATER DISTRIBUTION SYSTEM

The pumping plant which supplies the effluent to the irrigation application sites is located on the 24-inch pipeline that by-passes the Duck Pond (Figure 2). A sump which functions as a pump pit was installed at the by-pass line. Effluent in excess of that required by the pumps is permitted to continue out of the sump via the 24-inch line to Thompson Run, the normal disposal channel.

A pump house was constructed over the 10 x 10 x 8-foot sump. This house contains two pumping plants which are alternated manually, one serving as a standby. Each pumping plant includes a vertical centrifugal pump, designed for an output of 350 gallons per minute (gpm) at 520 feet (226 pounds per square inch) total head, and a 60 horsepower, 3-phase electric motor. The pump house also contains an in-line meter, which measures the amount of effluent pumped, and a pressure-recording instrument equipped with high and low pressure automatic signaling devices to indicate possible failures in the distribution or irrigation systems.

Leaving the pump house, a 6-inch steel pipe runs under Thompson Run and beneath a major highway (Pennsylvania Highway 26, Benner Pike). Beyond this, a 6-inch asbestos-cement line carries the effluent generally in a northwest direction. At a distance of two miles, the line divides: one 6-inch branch going a half-mile to the Agronomy and Forestry Areas, the other 6-inch branch going two additional miles to the Gamelands Area. All main lines are buried at least 18 inches. Since this depth is not adequate to prevent freezing, the effluent must be pumped continuously during cold weather. Appropriate vents and drains permit air removal and effluent drainage from the line when necessary.

The first branch line terminates at the Agronomy and Forestry Areas approximately two and one-half miles from and 175 feet higher than the pumping plant; the second branch line terminates in the Gamelands Area approximately four miles from and 280 feet higher than the pumping plant. The pump supplies approximately 350 gpm at 70 psi to the Agronomy and Forestry Areas or about 300 gpm at 45 psi to the high point in the Gamelands Area. The rate and pressure desired are regulated in each area by branch line valves.

IRRIGATION APPLICATION SYSTEMS

All pipe beyond the buried distribution system is above ground and comprises the irrigation application systems. These surface systems are composed of 4- and 5-inch aluminum main lines and 2- and 3-inch aluminum lateral lines, which distribute the effluent to regularly-spaced sprinklers on 1-inch diameter risers. The systems were designed to distribute 350 gpm or 500,000 gallons per day.

The typical irrigation application systems most frequently used during the first five years of operation are described in the report, Penn State Studies No. 23 (1). These systems ordinarily applied effluent to 3-acre areas at the rate of one-quarter inch per hour. For an application level of two inches per week, valve changes every 8 hours were required. One valve change each day occurred at midnight, which for a manually operated system was not convenient. Thus, to ease labor arrangements, to irrigate at a lower rate of application, and in some cases to permit the use of smaller lateral lines, the irrigation system was modified at some sites to allow a 12-hour period of application.

By appropriate use of specific sprinklers, spacing of the sprinklers along the laterals, spacing of the laterals, and adjustment of pressure at each lateral, application rates of one-sixth or of one-quarter inch per hour were provided at individual locations. For an application level of two inches per week only three acres need to be irrigated each 8-hour period or four and one-half acres each 12-hour period to use 0.5 mgd continuously. Each arrangement irrigates nine acres each day and thus, the system covers 63 acres in a week. The three-acre or four and one-half acre plots can be subdivided further to permit use of smaller diameter irrigation lines or to provide better hydrologic conditions. Most of the areas received two inches of effluent per week; however, various small experimental areas received one, four, or six inches per week (Table 3).

A solid-set irrigation system was used in all areas. That is, main and lateral lines were not moved from position to position, as is

Table 3. Monitored Irrigation Areas and Application System Parameters, 1963-1969

Location and Soil Series	Area No.	Vegetative Cover	Initial Irrigation Date	Irrigation Period	Weekly Load Inches	Sprinkler1/ Discharge gpm	Sprinkler Spacing Feet AxB2/	Area Acres
Agronomy (A)	1	Farm Crops	May, 1963	Apr-Oct	1	16.6	80x80	4.4
Hublersburg	2	Farm Crops	May, 1963	Apr-Oct	2	16.6	80x80	4.4
Clay Loam	3	Reed Canarygrass	July, 1964	Jan-Dec	2	16.6	80x80	16.0
Forestry (F)	1	Red Pine	June, 1963	Apr-Nov	1	6.23/	60x403/	1.0
Hublersburg	2	Red Pine	June, 1963	Apr-Nov	2	6.23/	60x403/	1.0
Clay Loam	3	Red Pine	July, 1964	Apr-Nov	2	6.2	60x40	13.5
	4	Hardwoods	June, 1963	Apr-Nov	1	8.3	80x40	0.5
	5	Old Field	June, 1963	Apr-Nov	2	8.3	80x40	0.5
Gamelands (G)	1	Hardwoods	Oct, 1964	Nov-Mar	24/	6.2	60x40	11.0
Morrison	2	Hardwoods	Oct, 1964	Nov-Mar	44/	6.2	60x40	3.0
Sandy Loam	3	Hardwoods	Nov, 1965	Jan-Dec	2	6.2	60x40	3.0
	4	Farm Crops	Nov, 1965	Jan-Dec	2	16.6	80x80	2.0

1/ Application rate was ¼ inch per hour for all systems.

2/ A = distance between sprinklers in line; B = distance between lateral lines.

3/ During 1963-67 sprinkler discharge was 8.3 gpm at a spacing of 80x40 ft above the canopy on risers which were 42 ft long.

4/ Weekly load was 6.0 inches in winter of '64-'65 and was followed by spring, summer, and fall irrigation, in 1965 only, at indicated loads. In subsequent years, through 1969, irrigation was only in Nov-Mar and both areas G-1 and G-2 received 4 inches weekly.

frequently done in agricultural crop irrigation. This permanent arrangement is preferred since it is difficult to move pipe among the trees; it is nearly impossible to move pipe when it is covered with ice; and the laterals used during winter need to be on a continuous grade to provide rapid draining during freezing weather.

Certain Agronomy and Forestry Areas were irrigated only during the period, mid-April through mid-November, (Table 3). Sprinkler heads in the Agronomy Farm Crop Areas were staggered, with a distance of 80 feet between sprinklers along the laterals and 80 feet between laterals. Each sprinkler emitted 16.6 gpm. Since this amount, on the average, was applied to each 80 x 80-foot area, the application rate was one-quarter inch per hour. A portion of the Reed Canarygrass Area had sprinklers placed on 80 x 100-foot spacings and applied the effluent at one-sixth inch per hour. The wider spacing is preferred since it permits lower original system costs and more convenient farming operations.

Table 3 also indicates the various spacings and application rates for the irrigation systems in wooded areas. Some of the variation was due to physical area restraints or for providing flexibility in the total system. On the basis of operational experience and of data presented in the irrigation systems operation section, the preferable spacing for wooded areas is 60 x 60 feet. This seems to give the best compromise between uniformity of distribution and cost of original equipment.

SITE CHARACTERISTICS

Physiography. The research area is located at the western edge of the Ridge and Valley section of the Folded Appalachian province. Youthful valleys of Spring Creek, Big Hollow, Buffalo Run and their dry tributaries are incised from 50 to 300 feet below rolling upland surfaces. Spring Creek is a rather small stream with a flow ranging from 10 to 990 cubic feet per second as it leaves the region. The stream drains the limestone Nittany Valley, and is fed by springs with flows up to 10 million gallons a day. The valleys except for Spring Creek are underdrained by solution channels developed near the top of several hundred to several thousand feet of dolomite and limestone bedrock. The water table underlies the valley bottoms from 10 to 75 feet below the ground surface. In adjacent uplands and along interfluves, the unconfined water table ranges from 50 to 325 feet below the surface. Big Hollow is a dry karst valley except for a few days of the year when runoff occurs along short segments of the valley. Buffalo Run Valley to the northwest of the disposal site has an influent stream which carries water during the spring and is dry the remainder of the year. Outcrops are present but sparse along the walls of the valleys. Uplands normally lack integrated drainage because differential weathering has produced a hummocky topography which retains surface water temporarily in depressions. Organic matter has accumulated in some depressions, helping to seal the bottoms and creating perched surface water ponds under normal rainfall conditions. Upland surfaces are covered by 5 to 161 feet of unconsolidated residues consisting of clay, silt and sand.

The range in thickness and composition of the weathered soil mantle, the character and thickness of bedrock strata, and the depth to the groundwater table were established through a drilling program initiated in May 1962.

Bedrock. The land on and adjacent to the research sites is underlain by a thick sequence of limestone and dolomite with inter-connected solution openings and cavities. Stratigraphic and structural studies (3, 4) were carried out to determine whether cavernous intervals are controlled by rock type, whether individual bedrock units serve as confining beds to groundwater movement, and whether solution zones are open or debris filled.

The rocks in the region of the effluent disposal sites were found to be structurally deformed into at least two anticlines (one of which is overturned) and a syncline. These deformities have more than 500 feet of closure. The northwestern border of the area is cut by several major thrust faults and by numerous minor normal and cross faults that extend into the area immediately adjacent to the irrigation sites. Most of the faults facilitated extensive weathering and are associated with zones of increased thickness of soil mantle. They also provide avenues for water movement.

Permeability of the faulted rock is 40 to 100 times greater than that of the adjacent sound bedrock. The Burmingham Thrust Fault, exposed along the northwestern margin of the study area, has a low angle dip to the southeast and completely underlies both disposal sites. At least two thrust faults are exposed in the outcrop area of the Burmingham Thrust. These undoubtedly converge at depth and give rise to a single, low-angle thrust fault. A significant volume of groundwater moves into this fault zone and flows northeastward toward Spring Creek.

Fracture traces--surface indicators of underlying, nearly-vertical zones of fracture concentrations--were found to be useful prospecting guides in locating zones of increased weathering, solution and permeability (5). Maximum solution development was found at or near the center of fracture traces. The permeability of fracture rock is 10 to 100 times that of adjacent unfractured rock. Fracture traces also delineate zones of more intense weathering, outlining regions where the soil mantle is 20 to 100 feet thicker than normal. Deep monitoring wells were located on these traces since they concentrate groundwater movement.

The rocks immediately underlying the disposal area comprise the Gatesburg Formation which has been subdivided in descending order into the dolomitic Mines Member, interbedded sandstones and dolomites of the Upper Sandy Member, dolomites of the Ore Hill Member, and interbedded sandstones and dolomites of the Lower Sandy Member.

Stratigraphic studies revealed that where sandstones occurred, cavities were localized and the mantle was thicker. Solution zones are concentrated along sandy-dolomite and dolomite-sandstone beds. These beds have a higher primary porosity and less total cement than adjacent, more dense dolomite beds and, hence, weathered more readily. Solution cavities were found to be more abundant in the highly-weathered upper 100 feet of bedrock.

In general, bedrock cavities were found to be of two types: a) solution cavities in dolomitic bedrock; and b) loose-to-friable zones and/or cavities in sandy dolomite to dolomitic sandstone beds. The first type is principally joint or fracture controlled. The second type occurs in sandstone beds from which the cement has been dissolved and is controlled by joints and fractures and by bedrock lithology. Cavities are generally five to twenty feet thick in the upper 100 feet of bedrock and less than one to three feet thick at greater depths. Shallow bedrock cavities connected to the weathered mantle appear to be filled with debris from the mantle. Their presence is commonly indicated by shallow depressions at the surface.

Extensive cavities were not encountered; rather, cavities are localized where joints, faults or fracture zones intersected bedding planes or porous strata. Groundwater is believed to flow from beneath the irrigation sites along a system of interconnected open joints, bedding planes, and fracture systems.

Three types of cavity-fill materials were distinguished: a) unsorted mixtures of sand, clay, and blocks of bedrock; b) sandstone rubble and/or sand containing varying amounts of silt and clay, and; c) clean, well-sorted silt and sand. The majority of bedrock cavities from which split-spoon samples were collected are above the water table and are of the first type. The fill was derived from slumping of the overlying weathered mantle. The second type of cavity-fill material is present in sandstone beds from which the cementing agents have been removed by weathering. The third type, recorded as "running sand" by drillers, lies below the water table in joints and in bedding-plane and solution openings. Most of the fill material serves as an additional adsorption and filtering medium for percolating water.

Weathered Mantle. The drilling program begun early in 1962 helped establish the range of weathering conditions which might be found at the potential sites. Test holes were drilled in uplands, adjacent to valley walls, along valley bottoms, and on topographic highs and lows.

Split spoon samples were obtained from the weathered mantle at one- to five-foot intervals and from bedrock cavities which were more than one to two feet thick.

A shallow seismic program was also conducted at the Agronomy and Forestry Areas to determine the soil thickness and configuration of bedrock suface. Measurements were made at 50-foot intervals along straight lines 520 feet long. A second test drilling program was carried out in the spring of 1963 to outline spots of thin soil cover within these areas and to confirm seismic interpretations.

The weathered mantle of the research areas was found to be composed of randomly occurring thin-to-thick beds of mixtures of clay, silt and sand which have accumulated as relatively insoluble residue from carbonate bedrock. Many of these beds have been truncated by surface erosion or draped into solution depressions within the bedrock surface and preserved against erosion. Chemically-resistant pebbles, cobbles and boulders of chert, nodular and bedded oolitic chert, quartzite, hematite-cemented sandstone, and fault breccia are distributed throughout the mantle.

The thickness of the weathered soil mantle was found to be greater above zones of increased solution. Dish-like depressions which concentrate water occur above these zones. Perched water tables persist for varying periods in more permeable beds below some of these depressions. At other positions above zones of increased solution, sink-holes have developed in which there is virtually no soil to retard the flow of water. Such depressions, if irrigated, would pose a hazard to the project since they could allow applied effluent to recharge directly to the groundwater.

Soils. Soils derived from the Upper and Lower Sandy Members of the Gatesburg Formation at the Gamelands Area are quite permeable and contain large amounts of sand. The Morrison sandy-loam and Gatesburg loamy-sand are two representative soil types derived from this rock and occupy most of the forested portions of the Gamelands Area. The cation and anion exchange capacities of these sandy-loam soils are less than that of the Hagerstown and Hublersburg silt loam and silty-clay loam soils derived from the Mines and Ore Hill Members of the Gatesburg Formation which are present in the cultivated portions of the Gamelands Area and cover most of the upland surface of the Agronomy and Forestry Areas. Detailed description of modal soil profiles of these soil types are given in (1).

Along segments of the dry bottoms of Big Hollow valley and its tributaries, weathering and erosion have extended through the Mines and Ore Hill Members into the top of the Upper and Lower Sandy Members of the Gatesburg Formation, resulting in isolated patches of Morrison or Gatesburg soils along the valley walls.

Groundwater. The orientation of most of the valleys tributary to Big Hollow and Buffalo Run is controlled by fracture traces, formational contacts, and fault zones. The position of Big Hollow is related to differential weathering of the eastward-dipping Mines Dolomite and the more soluble, overlying Stonehenge Limestone. The same condition that helped localize stream erosion helps capture surface water and convey it to solution zones beneath the valley. This surface runoff dissolves the underlying bedrock to produce open sink holes, which makes the valleys unsuitable for irrigation sites.

The water table in this region has relatively low relief and a nearly uniform gradient. It underlies uplands at depths of 100 to 350 feet. Thus, there is no danger of excessive surface waterlogging at the irrigation site due to a rising water table. Minor waterlogging may result from rising perched water-table levels.

Best estimates for the coefficient of transmissibility range from 100,000 to 150,000 gallons per day per foot (gpd/ft), as calculated from data obtained from wells located on fracture traces, and 1,000 to 4,000 gpd/ft in blocks of carbonate rock bounded by zones of fracture. These relatively high transmissibility values for solution zones combined with the relatively flat water table indicate that groundwater may move freely from the irrigation sites and other areas of groundwater recharge.

Prolonged drought combined with continued natural discharge and pumpage from wells in the area were undoubtedly responsible for water table declines in 1962-65. A rainfall deficit of 26 inches was recorded for this period by the Department of Meteorology at The Pennsylvania State University. At the same time, vast volumes of groundwater were discharged from springs into Spring Creek to the northeast. One of these springs has an approximate flow of 4,320,000 gallons per day. In addition, nearly two million gallons of groundwater were pumped each day from University wells. The pumping cone of depression around the University well field deepened during this dry period and expanded to divert more groundwater from the Agronomy and Forestry Areas. A groundwater divide at the Gamelands Area in 1962, the remnants of which are shown in Figure 4, completely dissipated and was replaced in 1965 by a groundwater trough (Fig 5) which marks a major subsurface drainage way. The unconfined water table in that area declined more than 60 feet in three years.

The presence of groundwater mounds beneath some topographic highs in 1962 prior to the drought, indicates that the uplands are recharge sites and that valley bottoms localize groundwater drains. For short periods of high runoff, localized and short-lived groundwater mounds build up beneath the valleys where normally groundwater troughs are located. The long-lived upland groundwater mound at the Agronomy and Forestry Areas, although subdued from May 1962, was still observed in April 1965. Groundwater flow was still away from this high in a radial manner.

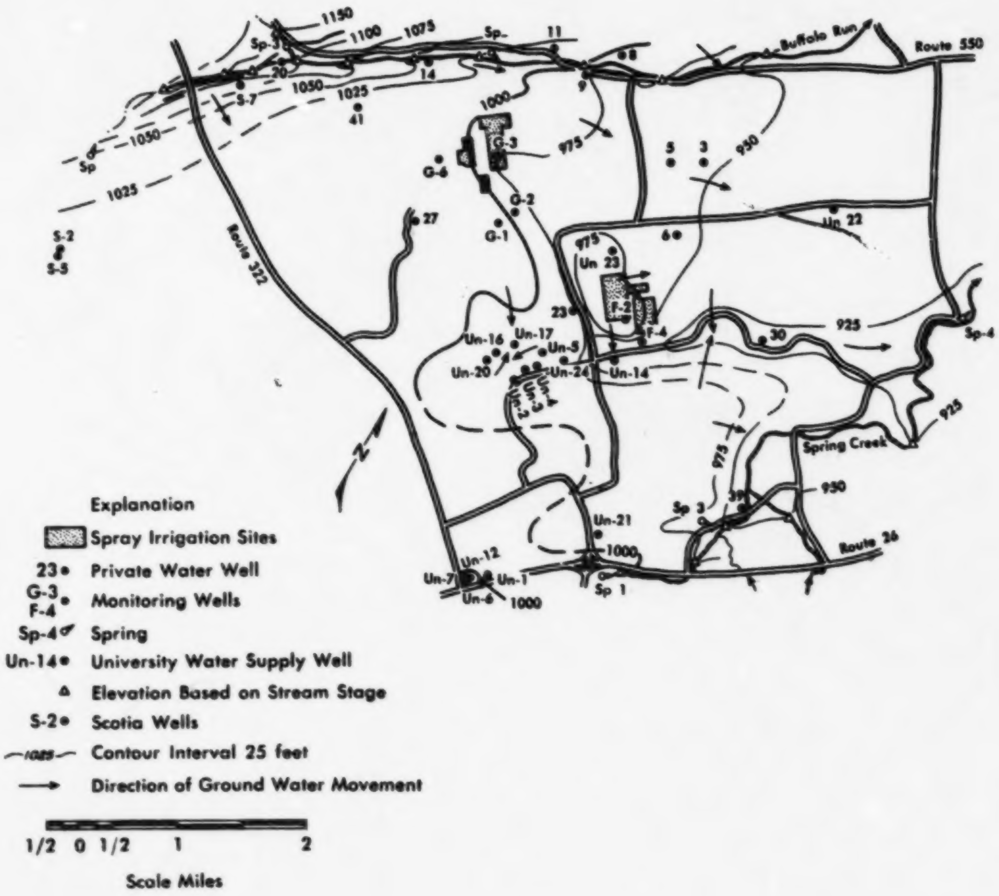

Route 550
Buffalo Run
Route 322
Route 26
Spring Creek
1150
1100
1075
1050
1025
1000
975
950
925
Sp-3
Sp
Sp-4
Sp 3
Sp 1
S-7
S-2
S-5
G-1
G-2
G-3
G-6
F-2
F-4
Un 22
Un 23
Un-16
Un-17
Un-5
Un-20
Un-24
Un-14
Un-4
Un-3
Un-2
Un-21
Un-12
Un-7
Un-1
Un-6
20
14
11
8
9
41
27
23
5
3
6
30
39
Explanation
Spray Irrigation Sites
23• Private Water Well
G-3, F-4 • Monitoring Wells
Sp-4 Spring
Un-14• University Water Supply Well
Δ Elevation Based on Stream Stage
S-2• Scotia Wells
1025 Contour Interval 25 feet
→ Direction of Ground Water Movement
1/2 0 1/2 1 2
Scale Miles

Figure 4. Water Table Contour Elevations in March, 1963.

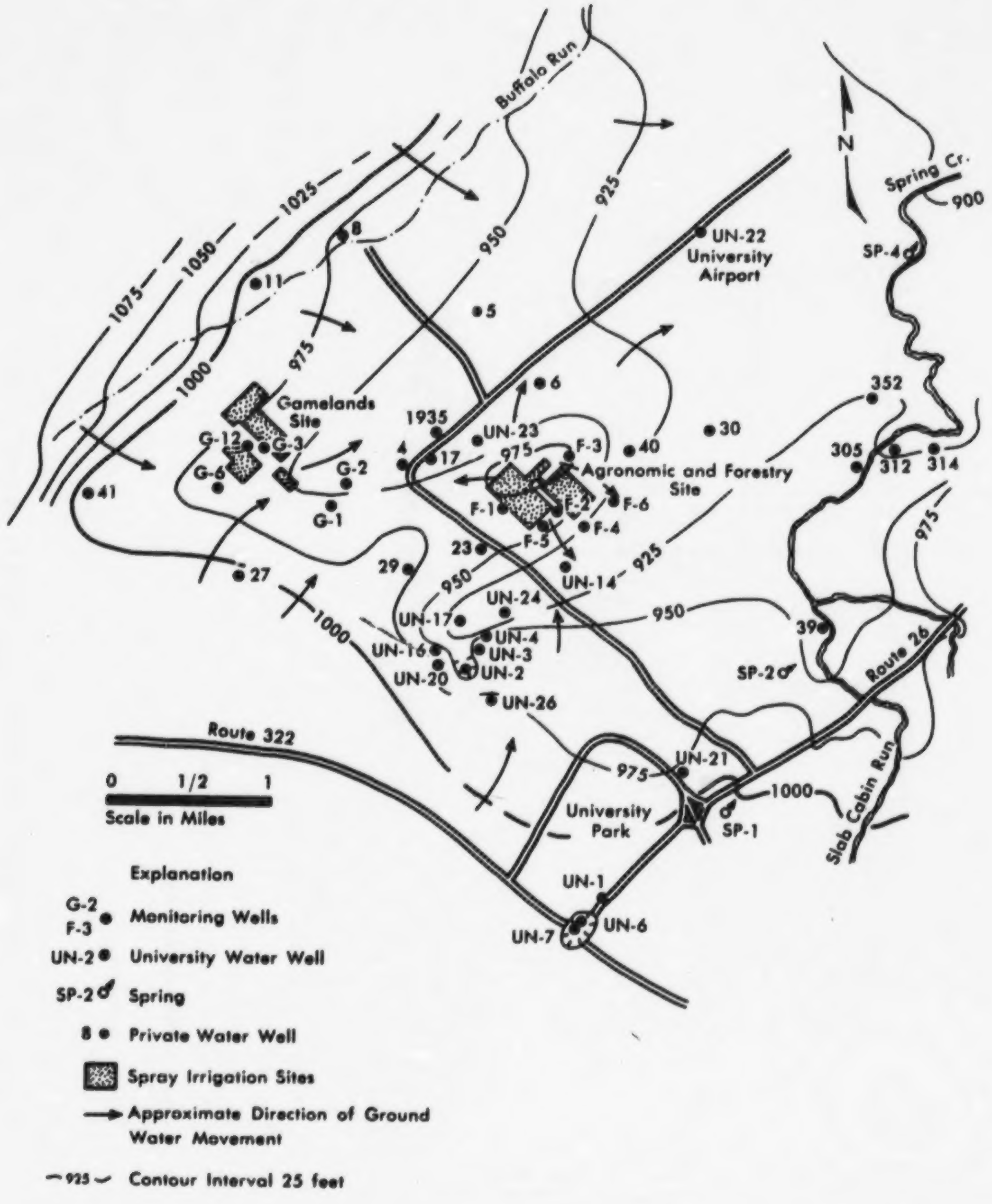

Buffalo Run
N
Spring Cr.
900
UN-22
University Airport
SP-4
1075
1050
1025
1000
975
950
925
8
11
5
6
352
30
40
305
312
314
Gamelands Site
G-12
G-3
G-6
G-2
G-1
41
1935
4
17
UN-23
975
F-3
Agronomic and Forestry Site
F-1
F-2
F-6
F-4
F-5
23
29
27
950
925
UN-14
975
UN-24
950
39
UN-17
UN-4
UN-3
UN-16
UN-20
UN-2
UN-26
1000
SP-2
Route 26
Slab Cabin Run
Route 322
975
UN-21
1000
University Park
SP-1
UN-1
UN-6
UN-7
0
1/2
1
Scale in Miles
Explanation
G-2 F-3 ● Monitoring Wells
UN-2 ● University Water Well
SP-2 Spring
8 ● Private Water Well
Spray Irrigation Sites
Approximate Direction of Ground Water Movement
925 Contour Interval 25 feet

Figure 5. Water Table Contour Elevations in April, 1965.

Vegetation. The two major disposal areas chosen for the disposal of effluent contained representative plots of forest, open fields, and cultivated croplands which allowed investigators to study the method under different vegetative conditions.

The forested portion of the Agronomy and Forestry Areas (Fig 6) includes approximately 70 acres of hardwoods and 90 acres of coniferous plantations, broken by open old-field areas.

The hardwoods at this site are primarily a mixture of white oak (Quercus alba L.), black oak (Quercus velutina L.), red oak (Quercus rubra L.), and scarlet oak (Quercus coccinea Muench), in association with a few hardwood species such as red maple (Acer rubrum L.), mockernut hickory (Carya tomentosa, Nutt), black cherry (Prunus serotina Ehrh), and flowering dogwood (Cornus florida L.). The average age of the dominant and co-dominant trees on the experimental plots was 50 years. The average tree diameter was 14 inches and the average height was 70 feet.

The coniferous plantations were established about 1939 on abandoned agricultural land. The trees were planted at a spacing of eight by eight feet. On the experimental plots of red pine (Pinus resinosa, Art.), the average tree diameter was 6.8 inches, the average height was 35 feet.

The cover in the open old-field areas was predominately a poverty grass (Danthonia spicata, Beauv.)-goldenrod (Solidago spp.)-dewberry (Rubus flagellaris, Willd.) plant community. One sparse stand of 9 year old white spruce (Picea glauca, Moench) was also in the experimental area. Deer damage to the spruce by browsing has been extensive. Height of the white spruce in 1963 ranged from 2 to 10 feet. The average height of twenty paired sample trees used to measure response to irrigation was 6.8 feet.

Most of the adjacent Agronomy Area (approximately 70 acres) has been managed by the University in a rotation consisting of corn, oats, wheat, and one or more years of hay. A portion, however, has been kept in a permanent hay cover (reed canarygrass). The rotation hay crops were timothy and red clover or timothy and alfalfa.

The Gamelands Area contains approximately 200 acres of mixed hardwood forest. The vegetation was composed largely of oaks, predominantly white. The average diameter of 60 paired trees selected for measurement was 10.4 inches with an average age of 40 years and an average height of 50 feet. Ground cover was sparse.

MONITORING SYSTEMS

A diversified monitoring system was considered an essential part of this feasibility study in order to learn the degree of renovation of

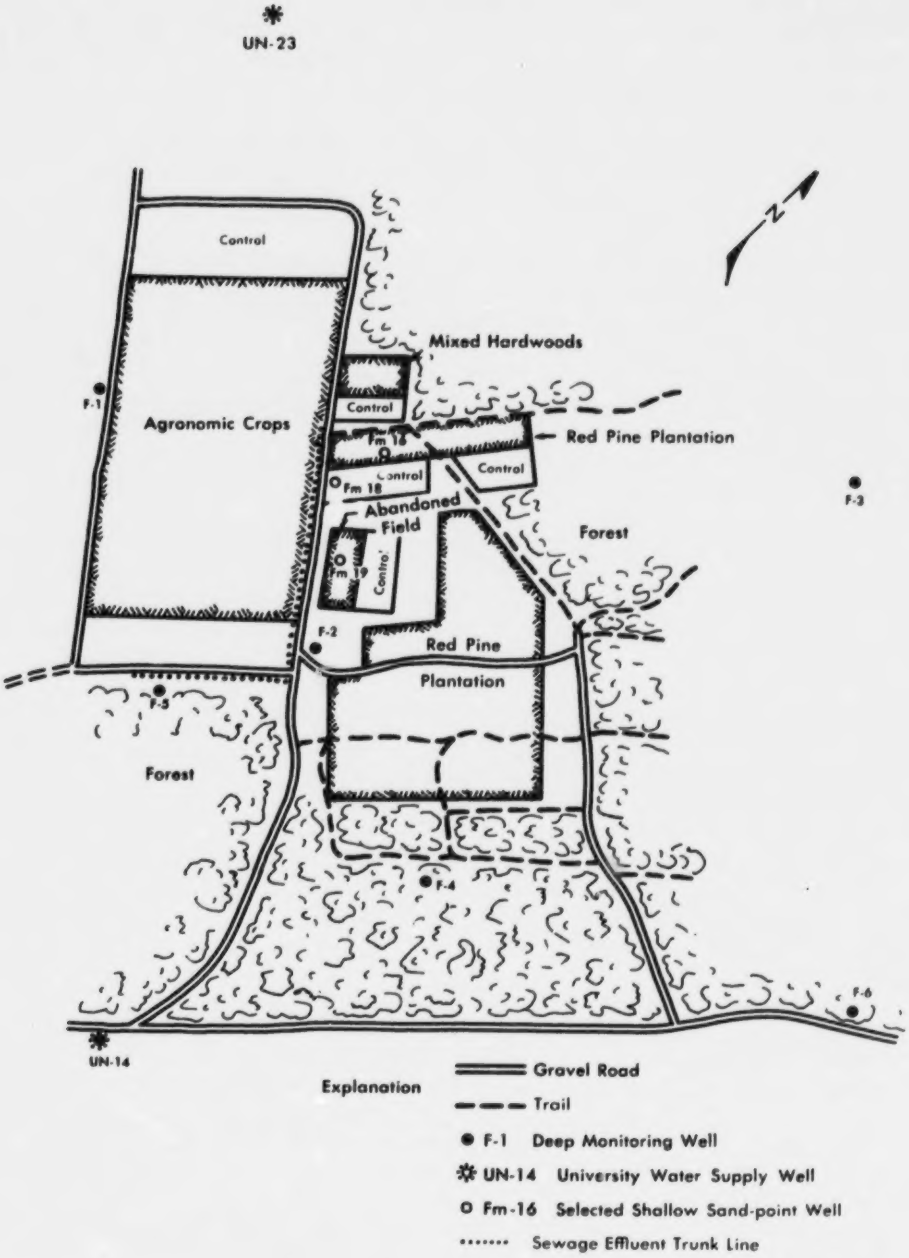

UN-23
Control
Mixed Hardwoods
F-1
Agronomic Crops
Control
Red Pine Plantation
Fm 16
Control
Fm 18
Control
Abandoned Field
F-3
Forest
Fm 19
Control
F-2
Red Pine
Plantation
F-5
Forest
F-4
F-6
UN-14
N
Explanation
Gravel Road
Trail
F-1 Deep Monitoring Well
UN-14 University Water Supply Well
Fm-16 Selected Shallow Sand-point Well
Sewage Effluent Trunk Line

Figure 6. Layout of the Agronomy and Forestry Areas.

wastewater with depth of penetration in various soils within and below the root zone and the quality of water being recharged to the ground-water reservoir.

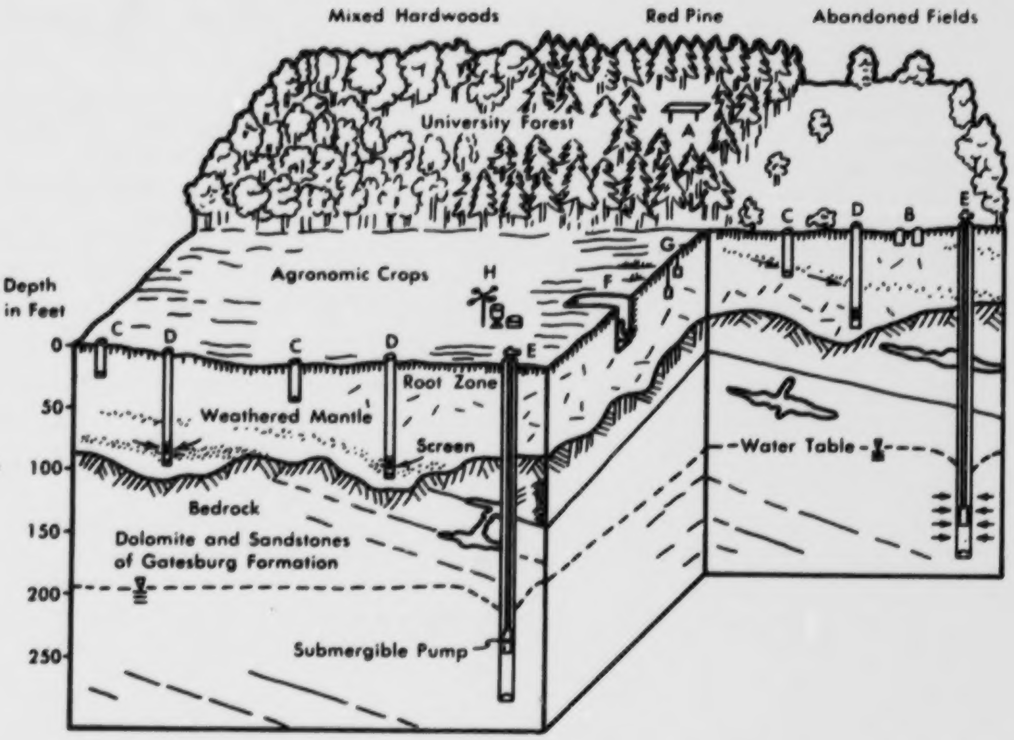
Both an onsite soil-water and ground-water sampling network and an offsite network of private and public wells and springs were part of the monitoring system. A schematic diagram of the various types of monitoring installations is shown in Figure 7.

Effluent Gauges. Throughfall rain gauges were used to determine the amount of wastewater reaching the forest floor in the red pine plots when sprinklers were above the tree canopy. Six of these gauges, each 5 inches wide, 48 inches long, and 6 inches deep, were placed at random in the 1-inch and 2-inch red pine treatment plots. The gauges were installed with a slight gradient toward the drainage outlet and were supported approximately 2.5 feet above the ground surface on two wooden stakes. They were connected to 5-gallon collection cans with rubber tubing.

Two small capacity rain gauges were placed beside each forest floor pan and pan lysimeter. These were used to obtain an accurate measurement of the amount of wastewater reaching the forest floor and vegetative cover at the location of the percolate sampling instruments.

Forest Floor Pans. Cylindrical pans, each two inches in height with an exposed surface area of 500 square inches, were filled with an undisturbed sample of the forest floor (litter, fermentation and humus layers). A gradient of approximately five per cent was maintained toward the drain outlet. The filled pans were installed at ground level in as natural a condition as possible. The percolate samples were collected in a 3-gallon glass jug which was connected to each pan by a rubber tubing. Two of these floor pans were filled and installed in each treatment and control plot of the hardwood stands and red pine plantation. The two pans installed within the control plot of the red pine 2-inch application area served as controls for both red pine treatment plots.

Pan Lysimeters. Pan lysimeters measuring 12 x 15 inches were constructed of 16-gauge galvanized sheet metal with a drainage outlet of one-half inch copper tubing. A pit was excavated deep enough to accommodate 10- and 20-gallon galvanized steel garbage cans and the pans were inserted into the undisturbed face of the soil profile with a gradient toward the outlet of approximately one inch per foot. The cans were placed in the pit and the copper tube spouts were inserted into the cans. After backfilling the pit around the cans, the forest floor was replaced in its original position. A 4-quart plastic container was placed in each can beneath the copper tubing to collect the percolate. Samples were collected after each irrigation and each storm.


Mixed Hardwoods
Red Pine
Abandoned Fields
University Forest
A
Agronomic Crops
H
G
F
C
D
B
E
Depth in Feet
0
50
100
150
200
250
Root Zone
Weathered Mantle
Screen
Bedrock
Dolomite and Sandstones of Gatesburg Formation
Water Table
Submergible Pump

- A. Throughfall gauge
- B. Lysimeters (In root zone at depth of 1½ inches to 4 feet).
- C. Soil Moisture Access Tubes (To measure changes in soil moisture— 8 to 20 feet deep).
- D. Sand-point Wells (completed in the weathered mantle at depths from 6 to 52 feet).
- E. Deep Water-table Wells (Contain submergible or piston pumps, 250 to 300 feet deep).
- F. Trench with pan lysimeters at one foot intervals to depths 6 and 16 feet.
- G. Suction lysimeters, 6 inches to 26 feet in depth
- H. Weather Station

Figure 7. Schematic Diagram of Various Types of Monitoring Installations.

The lysimeter pans were placed at depths of six and twelve inches in the hardwood area receiving one inch of wastewater per week, in the red pine area receiving two inches, and in the old field area receiving two inches per week. Similar pans were installed at three and six inches in the red pine area receiving one inch of wastewater per week.

Pan lysimeters were also installed along the walls of a six foot deep trench in the Forestry area where effluent was applied at the rate of 4-inches per week during the growing season and in a 17-foot trench in the Gamelands where 4-inches per week was applied during the winter. They were installed at depths of one-half, one, two, three, four, five, and six feet in the 6-foot trench, and at one foot intervals from one to sixteen feet in the 17 foot trench.

The trench walls were braced with timbers and siding treated with liquid wood preservatives to prevent decay and to insure longer integrity of supporting members. The seepage face was inclined 1 to 5 degrees from the vertical and sloped toward the direction where interflow was expected. Metal pans were driven into the seepage face and small voids above and below the pans which were created during insertion were back-filled with native soil. Voids between the trench face and protective siding were backfilled with soil and pea gravel to allow soil water to flow freely to the pit floor (Fig 8 and 9). Both pits were covered with a sloping roof and later the 17-foot trench was provided with a wooden floor after the bottom began to heave.

Parizek and Lane (6) pointed out the limitations and problems encountered with this method of sampling soil water. During the first winter (1964-65), 6-inches of wastewater per week were applied to the slope above the sampling pit in the Gamelands. After 12-inches of water had been added, underflow became excessive and the pit was flooded nearly to the roof by perched groundwater within a few hours. To protect the sampling station, and avoid contaminating the soil adjacent to the pit, a 90 foot deep floor drain was drilled and cased to underlying dolomite. In subsequent years, when only four inches or two inches were applied weekly, pit flooding did not occur.

The stratified nature of these residual soils, sloping character of land, and large amounts of wastewater applied along the slope above the trench lysimeter, helped to account for flooding problems encountered. A sump pump or floor drain would probably be required to prevent flooding under similar circumstances particularly where more than 2-inches of water a week in addition to rainfall are applied in a humid region.

It was found that gravitational water samples could be obtained only rarely from the trench lysimeters during the growing season when water

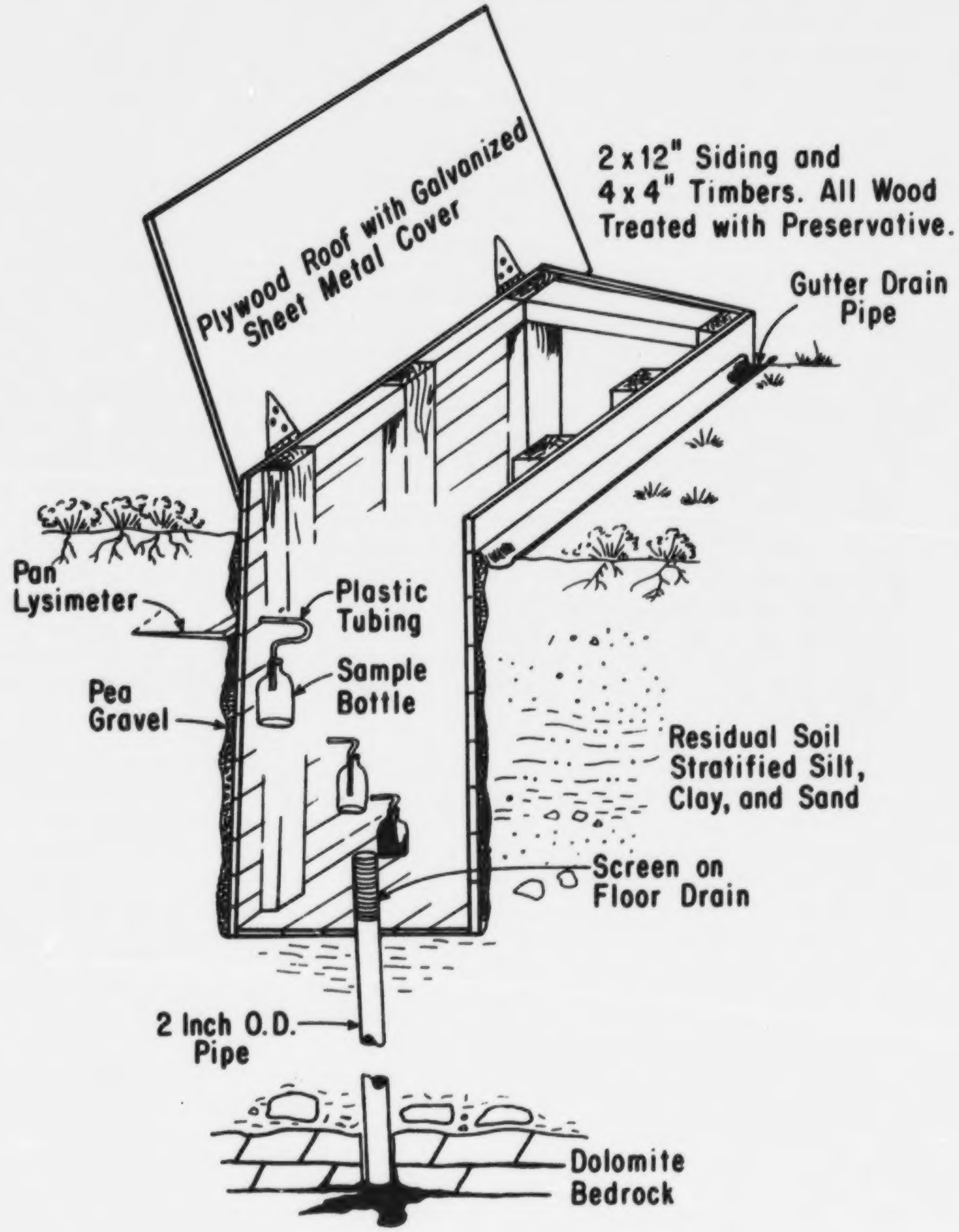

Plywood Roof with Galvanized Sheet Metal Cover
2 x 12" Siding and 4 x 4" Timbers. All Wood Treated with Preservative.
Gutter Drain Pipe
Pan Lysimeter
Plastic Tubing
Sample Bottle
Pea Gravel
Residual Soil Stratified Silt, Clay, and Sand
Screen on Floor Drain
2 Inch O.D. Pipe
Dolomite Bedrock

Figure 8. Schematic Diagram of Trench Lysimeter.

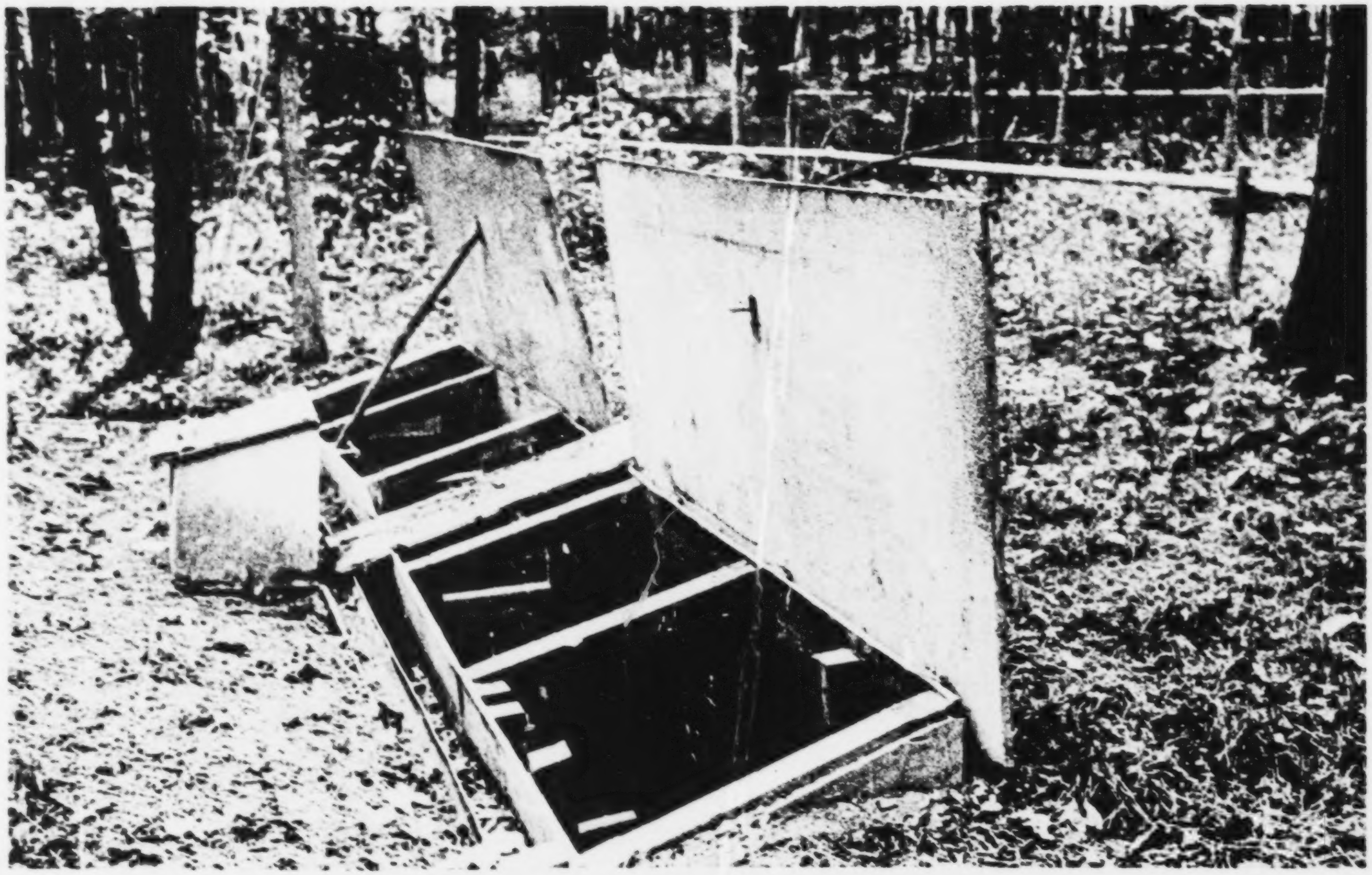


Figure 9. Oblique View of Trench Lysimeter. Irrigation Lines in the Background Have a Two Percent Grade to Provide Rapid Drainage to Prevent Freezing in the Winter.

was not being applied in the immediate area. By 1968 all pan lysimeters were replaced by suction lysimeters in the forest areas because there were several indications that the pans had rusted out.

Sand-Point Wells. Some exploratory test holes drilled to determine the thickness and composition of the weathered soil mantle were used as intermediate sampling points. Two-inch diameter steel pipes fitted with 2 foot long sand-point screens were installed in these bore holes. Approximately half of these wells were located beneath surface depressions where the weathered soil mantle was draped into solution openings within the underlying bedrock and where runoff and side hill seepage might be excessive. These wells are completed in sand or silt lenses within clay that contain intermittent perched groundwater, at depths of six to 60 feet as a result of subsurface flow. The 3-inch diameter test holes were back-filled almost to the base of a selected sandy-clay or silt bed. A 2-inch diameter, 2-foot long Johnson well-screen was attached to the top of a three foot long reservoir pipe. The lower reservoir pipe and overlying casing were embedded in a mixture of bentonite and native clay and washed silica sand was placed opposite the screen. Each installation was flushed with well water to remove clay in the vicinity of the screen. Water samples were obtained by hand-bailing.

This method of sampling soil water was found to be of marginal value. Perched groundwater did not form at all sampling locations. Abundant volumes of water were available in some, in others, only occasional samples could be obtained. Frequently, the sample volume was insufficient for the analyses to be performed.

Sediment entrained with the water posed analytical problems. The screen slot size was sufficiently large to allow clay-sized material to enter the sampling point. Also the mechanical bailing method aggravated the problem by causing a surging action. A sand pack could be designed to eliminate the sediment problem but a large diameter hole, greater than 3-inches, would be required. Less surging would result if a small capacity pump were left in place. An air-back pressure method of pumping was tried but air freely entered the formation and escaped to surface outside the steel casing before water was forced to surface on a consistent basis.

Despite these shortcomings, water samples were routinely collected from a number of sand points at the Agronomy-Forestry Site.

Suction Lysimeters. Suction lysimeters, also referred to as vacuum lysimeters, are used to obtain soil-water samples at shallow depths, 6 inches to 4 feet, and to depths of 26 feet or more at the research sites. The devices used for shallow sampling are similar to that described by Wagner (7), and were first installed by Kardos in 1964 in the Agronomy Area and later replaced the pan lysimeter in the forest areas. The method of installation is described in Edwards (8). The suction lysimeters consist of a porous ceramic cup having an outside diameter of 1 7/8 inches and an overall length of 2 7/8 inches. The cup is cemented to plastic tubing to provide an air and watertight seal. When the porous cup is moist it will hold a vacuum equivalent to the vapour pressure of the water. The top of the plastic pipe is plugged with a one-hole or two-hole rubber stopper. Rigid tubing is inserted through the stopper and is fitted externally with a short length of rubber tubing. With the one-hole stopper a vacuum is applied to the assembly and maintained by closure with a thumbscrew clamp applied to the rubber tube. To recover water samples, the screw clamp is released, a small diameter rigid tube is inserted through the rubber tubing and a vacuum is applied through a flask which collects the water as it is withdrawn (Fig 10a). When using a two-hole stopper, one of the rigid tubes, both of which are cut off just below the stopper, is fitted with a length of tubing which extends to the inside bottom of the ceramic cup. To evacuate the chamber the connection is made to the rigid tube which ends just inside the stopper. To remove the sample from shallow positions suction is applied to the tube which extends to the bottom of the chamber after opening the tube which ends just inside the stopper.

This unit was modified by Parizek to allow soil-water samples to be collected from depths greater than 20 feet. A detailed description of this modified device is given by Parizek and Lane (6) and is shown in Figure 10-b. Several dozen of these devices were installed at depths of three to twenty-six feet below ground surface at the Gamelands site. Many have been in use for six years or longer and are still in good operating condition. More recently they have been shown to be suitable for obtaining soil water samples from below a 60 foot depth at another research project site.

Because of the extremely fine porosity of the ceramic cups soil-water samples collected from suction lysimeters may not contain representative concentrations of particulates such as bacteria and suspended solids. Also when studying trace elements in soil water, care must be exercised when selecting tubing, grout, plastics and the like for these may contain impurities which might contaminate the sample.

Deep Monitoring Wells on Site. To increase the probability of obtaining representative samples of groundwater leaving the irrigation sites, nine deep wells were drilled on fracture traces or at fracture-trace intersections where groundwater flow is concentrated. The wells were drilled either three inches or two and three-eights inches in diameter to depths from 100 to 370 feet. The wells were sampled with a mechanical hand-bailer for the first year. Six of the wells at the Agronomy-Forestry Area were equipped with Reda electrical submergible pumps. All but one of these became sand-locked shortly after

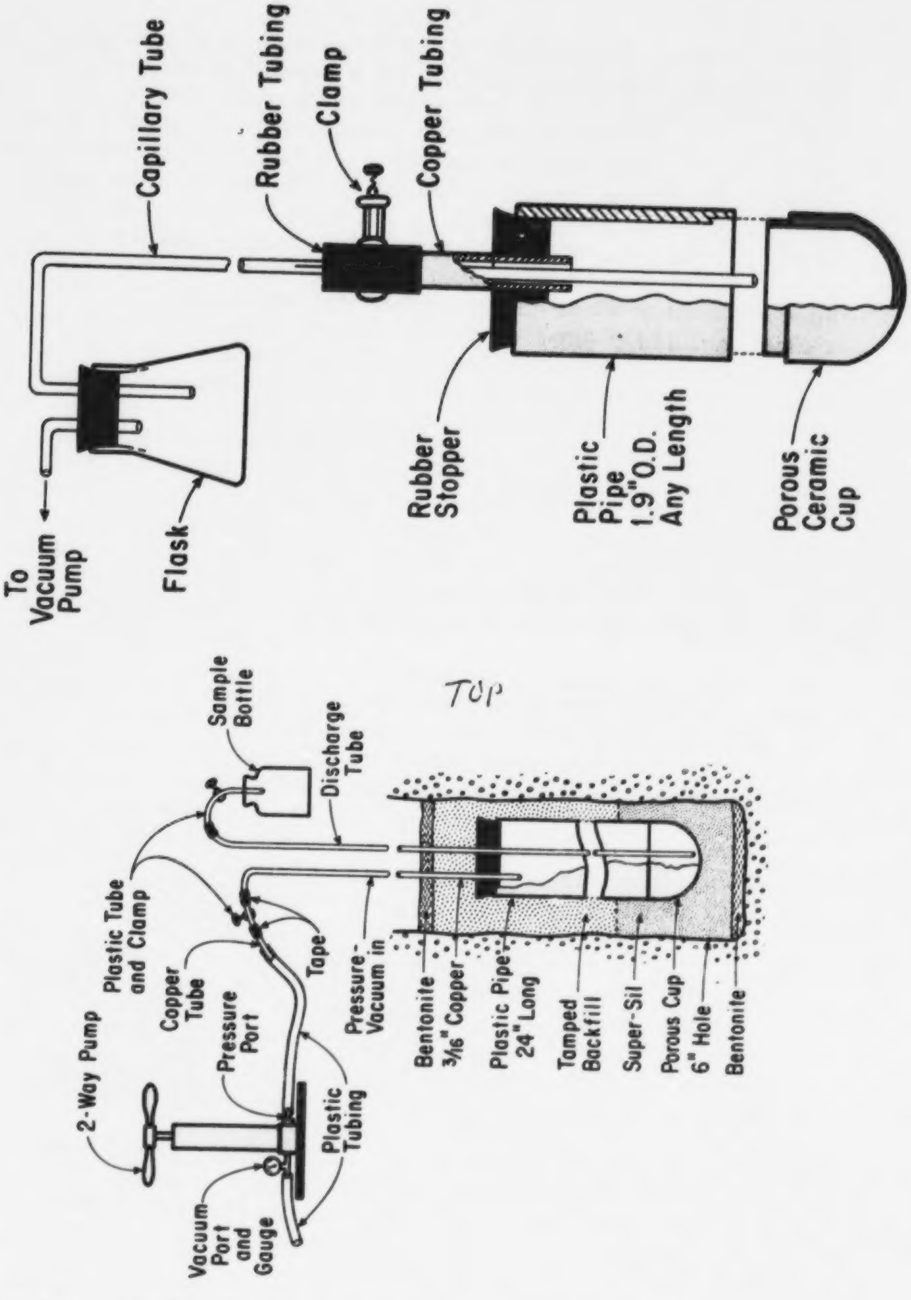

To Vacuum Pump
Flask
Capillary Tube
Rubber Tubing
Clamp
Copper Tubing
Rubber Stopper
Plastic Pipe 1.9"O.D. Any Length
Porous Ceramic Cup
TOP
Sample Bottle
Discharge Tube
Plastic Tube and Clamp
Copper Tube
Tape
Pressure Port
2-Way Pump
Plastic Tubing
Vacuum Port and Gauge
Pressure-Vacuum in
Bentonite
3/16" Copper
Plastic Pipe 24" Long
Tamped Backfill
Super-Sil
Porous Cup
6" Hole
Bentonite

Figure 10. Suction Lysimeter Equipment for Sampling Shallow Soil Water (a) and Modified Equipment for Sampling Deep Soil Water (b).

installation by fine silt and sand derived from solution openings. These pumps were replaced by Myers-type, single and double-acting piston pumps capable of delivering 2 to 4 gpm from depths to 300 feet. These were driven with 2-horsepower gas engines. In two wells, 2 3/8-inch casing was set into 3-inch cased holes to screen out flowing sand. The end of the casing was fitted with two, 2-foot lengths of slotted Johnson well-screen capped at the bottom. A single-acting pump barrel and copper air line were installed inside the 2 3/8-inch casing to a depth just above the screen.

Water levels were measured by the air-line method. Three-sixteenths-inch copper tubing was used for the air lines in the 3-inch holes and one-eight inch copper tubing was used in the 2 3/8-inch holes. Drop-pipe couplings had to be grooved to make room for the air-lines because of the small amount of clearance between the casing and drop-pipes. In most cases copper air lines became pinched with time or were sheared off by the vibration of pump drop pipes.

Groundwater monitoring wells also should be designed to collect representative samples of reclaimed wastewater. This can be a problem particularly where seasonal water table fluctuations are pronounced (30 or more feet). Deeply cased wells, for example, may sample water recharged in an adjacent region which underlies wastewater recharged at the irrigation site. Such a monitoring well will not provide data representative of the recharged renovated wastewater (Fig 11).

Off Site Wells and Springs. An intensive program of monitoring of private and public water supply sources was established in April of 1962 to determine the pre-test conditions and natural seasonal variations in quality of water in the area. Sampling sites included 44 private wells, five University-owned wells, six springs, and Buffalo Run Stream, the main drainage course of Buffalo Run Valley northwest of the project area. The identification of the wells and springs is shown in Appendix B and their geographic location is shown in Figure 2.

The sampling program was continued at 1-month intervals for the period April 1962 to April 1963, and at approximately 2-month intervals until 1968 and less frequently since that time. New wells have been added to the survey from time to time and in some instances wells became dry or sampling was discontinued. Inventory of off site water supplies in advance of initiating irrigation projects is of value to establish background conditions.

Soil Moisture Access Tubes. Thin-walled, steel tubes were installed to 20-foot depths in various irrigation plots and adjacent control plots. These were used to monitor the movement of water through the soil mantle by the neutron scattering method. All sites were calibrated by determining the soil moisture content of samples collected at 1-foot intervals during drilling. Bulk density determinations on

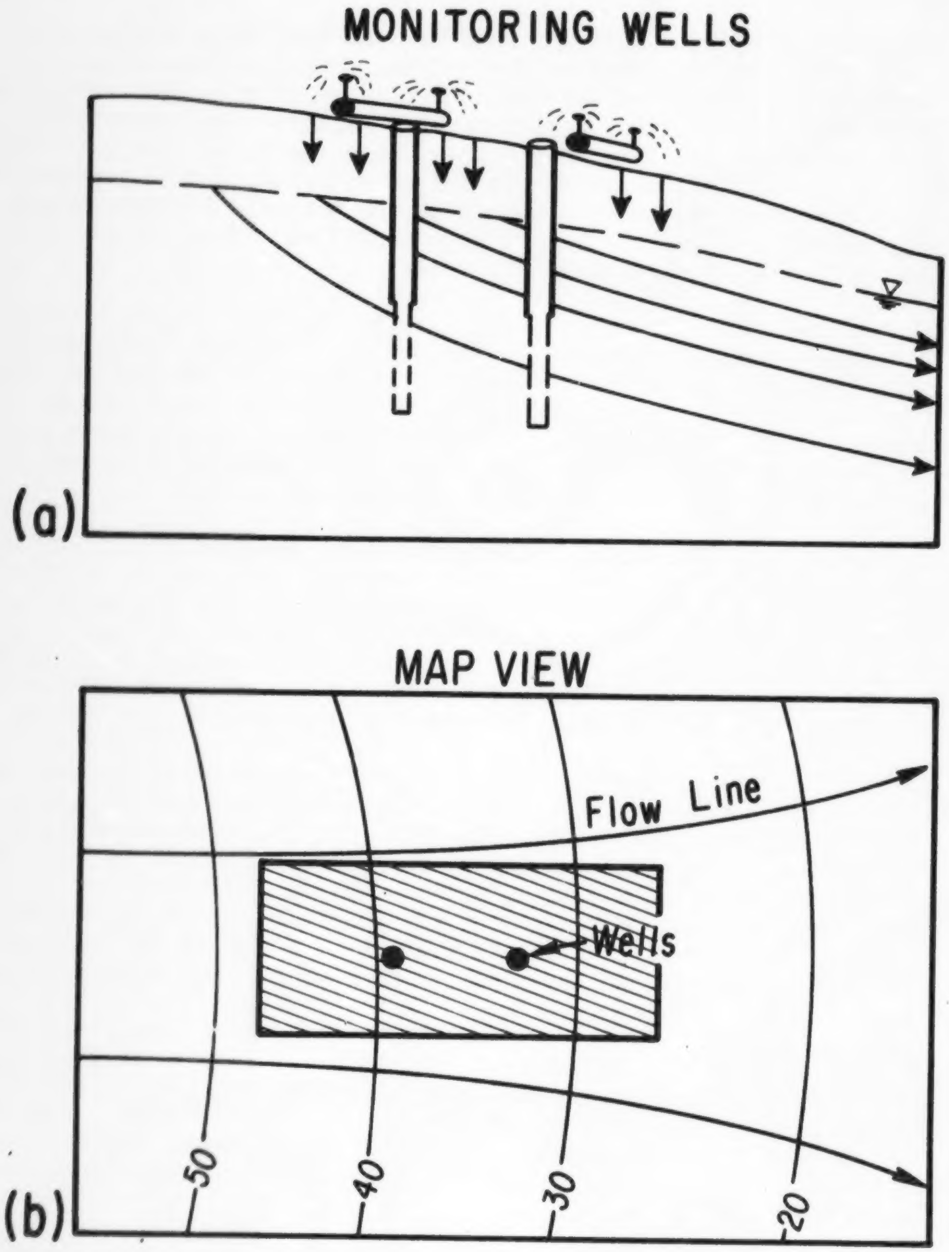

MONITORING WELLS
(a)
MAP VIEW
Flow Line
Wells
50
40
30
20
(b)

Figure 11. Monitoring Wells Drilled and Cased Below Streamlines Containing Renovated Sewage Effluent. In Mapview (b) Wells Appear to be Properly Located.

samples from the Agronomy and Forestry Areas were made by the mercury immersion method and these were compared with field measurements taken in place by a Nuclear-Chicago gamma radiation device.

Soil Samples. At the time of installation of the soil moisture access tubes, soil samples were obtained at 1-foot intervals to 20 feet or to bedrock, whichever came first. Part of the samples was used for determining soil moisture at the time of installation and for bulk density determinations. The remaining soil material was composited over 5-foot intervals for chemical analysis.

Soil samples were secured at various times at 1-foot intervals to a depth of five feet from all Agronomy and Forestry experimental plots. These samples were air-dried, crushed to pass a sieve opening of 2 mm for chemical analysis. Soil samples were also obtained at various depths for special studies, both physical and chemical.

Weather Station. Two climatic stations were established specifically for the project, one in the vicinity of each irrigation site. Instruments collected data on precipitation, humidity, temperature, solar radiation, and wind velocity.

SECTION V

IRRIGATION SYSTEM OPERATION

SPRINKLER TESTING AND DEVELOPMENT

Preliminary testing of irrigation systems which could operate throughout the winter months and yet offer reasonable distribution patterns was done in 1963-64. Both surface and sprinkler irrigation type distribution methods were tested and the major results discussed in Penn State Studies No. 23 (1).

A 14-acre area in the Gamelands was first irrigated during the winter of 1964-65 (10) using commercial and modified sprinklers. Test results during this winter indicated that stationary deflector sprinklers operated exceptionally well even when temperatures dropped below zero. The distribution pattern of this type sprinkler, however, was not as uniform as desired. Results of that year's test work have also been reported (1).

Two additional studies of sprinklers for distributing effluent during freezing conditions were made. The first of these (1965-66) was on the development of stationary-orifice, rotating-deflector sprinkler heads (11). The sprinklers in this study used essentially the same type of base as the stationary deflector sprinkler of 1964-65; however, they used various types of frameworks above the base which permitted the cone-shaped deflector to rotate hydraulically, Figures 12 and 13.

Extensive preliminary testing was conducted to establish rotor design criteria for obtaining the optimum distribution pattern. Rotor diameters of 1.5 and of 2.0 inches were chosen and each of these was tested with three different slot design criteria. The purposes of the slots were to produce proper rotation of the rotor and to aid in the uniform distribution of the effluent. Three replicated distribution tests using multiple sprinkler heads were conducted to determine the uniformity coefficients of the distribution patterns produced by each rotor configuration. These results are listed in Table 4 and show that the best distribution was obtained with the 2-inch rotor having 3/16-inch wide slots cut into the rotor face. However, uniformity of distribution was substantially poorer than with conventional rotating sprinklers which have a uniformity coefficient of 75 to 80%.

The distribution pattern of the rotating-deflector sprinklers was appreciably better than that of the stationary deflectors as long as the rotors continued to turn. During the winter tests, however, it was found that only 27 percent of them rotated during every run, while 8 percent never rotated and the other 65 percent varied from rotation to non-rotation from week to week. It is believed, however, that efficiency of turning could be greatly improved if the machined parts were more finely finished.

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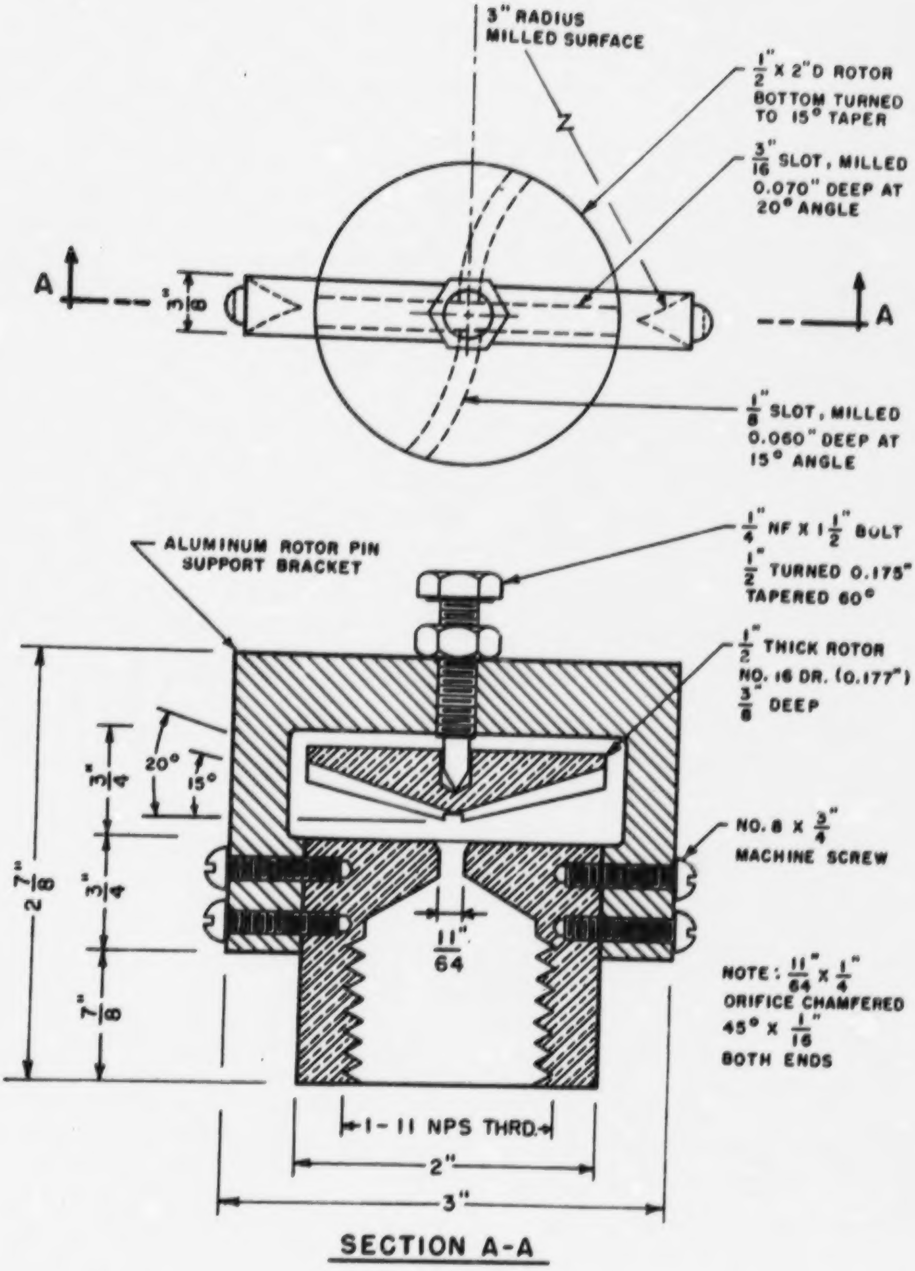
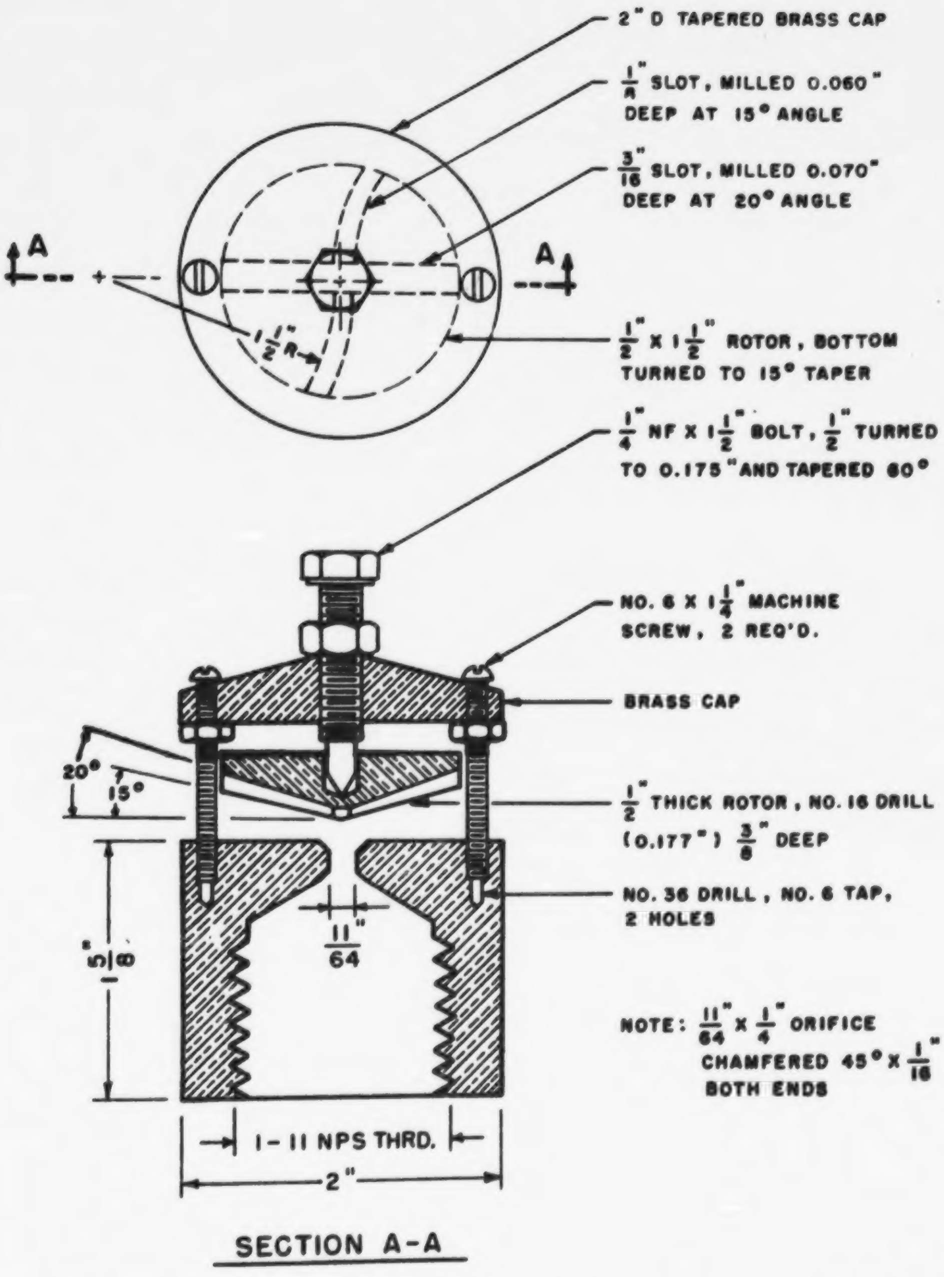

3" RADIUS MILLED SURFACE
Z
1/2" x 2"D ROTOR BOTTOM TURNED TO 15° TAPER
3/16" SLOT, MILLED 0.070" DEEP AT 20° ANGLE
A
3/8"
A
1/8" SLOT, MILLED 0.060" DEEP AT 15° ANGLE
ALUMINUM ROTOR PIN SUPPORT BRACKET
1/4" NF x 1 1/2" BOLT
1/2" TURNED 0.175" TAPERED 60°
1/2" THICK ROTOR NO. 16 DR. (0.177") 3/8" DEEP
20°
15°
3/4"
3/4"
2 7/8"
7/8"
NO. 8 x 3/4" MACHINE SCREW
11/64"
NOTE: 11/64" x 1/4" ORIFICE CHAMFERED 45° x 1/16" BOTH ENDS
1-11 NPS THRD.
2"
3"
SECTION A-A

Figure 12. Model I - 2 Inch Rotor Sprinkler (11).



2" D TAPERED BRASS CAP
1/8" SLOT, MILLED 0.060" DEEP AT 15° ANGLE
3/16" SLOT, MILLED 0.070" DEEP AT 20° ANGLE
A
A
1 1/2" R
1/2" x 1 1/2" ROTOR, BOTTOM TURNED TO 15° TAPER
1/4" NF x 1 1/2" BOLT, 1/2" TURNED TO 0.175" AND TAPERED 60°
NO. 6 x 1 1/4" MACHINE SCREW, 2 REQ'D.
BRASS CAP
20°
15°
1/2" THICK ROTOR, NO. 16 DRILL (0.177") 3/8" DEEP
NO. 36 DRILL, NO. 6 TAP, 2 HOLES
1 5/8"
11/64"
NOTE: 11/64" x 1/4" ORIFICE CHAMFERED 45° x 1/16" BOTH ENDS
1-11 NPS THRD.
2"
SECTION A-A

Figure 13. Model II - 1.5 Inch Rotor Sprinkler (11).

Table 4. Summary of Uniformity Coefficients from Rotor Design Tests (11)

Sprinkler Model	Designation			Uniformity Coefficient[a]
	Rotor Diam.		Slot Width	
I	2.0	x	1/8	34.48
				42.26
				43.96
				Avg. = 40.23
I	2.0	x	3/16	49.65
				47.89
				41.95
				Avg. = 46.50
I	2.0	x	1/4	37.87
				29.63
				33.77
				Avg. = 33.76
II	1.5	x	1/8	18.56
				17.81
				21.67
				Avg. = 19.68
II	1.5	x	3/16	28.57
				27.13
				26.53
				Avg. = 27.41
II	1.5	x	1/4	17.02
				26.05
				12.55
				Avg. = 18.54

[a] Uniformity coefficient = $100(1 - 0.798 \frac{S}{\overline{X}})$; where S is the standard deviation and $\overline{X}$ is the population mean. (12)

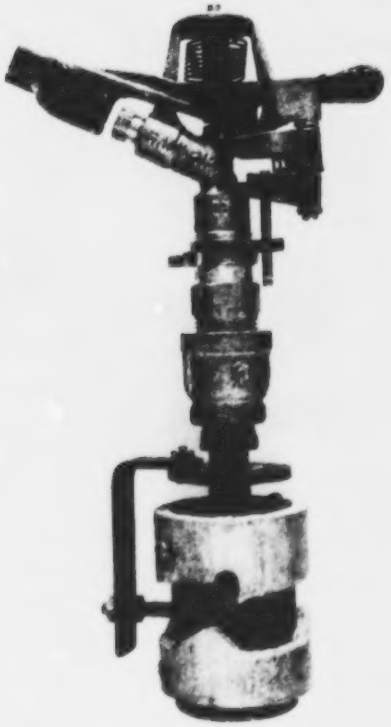


Figure 14. Indexed Position, Part-Circle Sprinkler, Rainbird Model 35-PJ, Types E and F. (13)

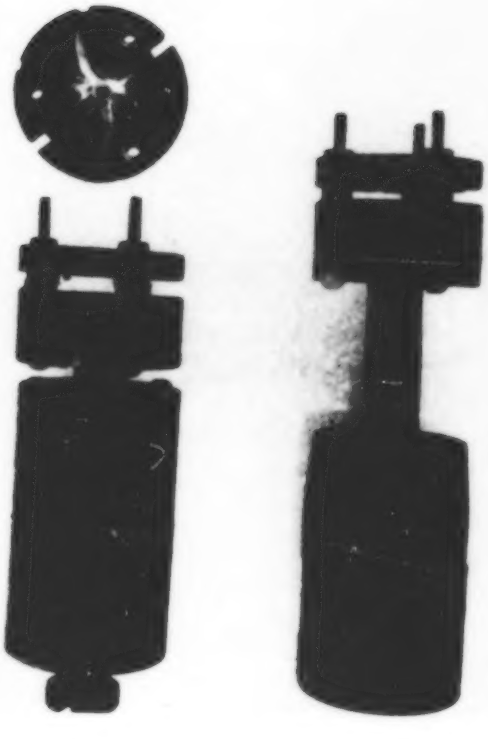


Figure 15. Random Indexing, Grooved Deflector Sprinkler, Type C. Upper Left View Shows Deflector; Lower Left View Shows Sprinkler Position When Not Operation; Right View Shows Sprinkler in Operating Position. (13)

The second study (1967-68) was done on the development of sprinklers to provide both satisfactory distribution and the penetration of existing ice or snow ground cover (13). An indexing mechanism was developed to control the position of a part circle sprinkler during successive runs, Figure 14. This sprinkler concentrated its discharge over a specified sector of a circle during one run, for the next run it advanced 120 degrees for irrigating another sector of the circle, and so on. Even though the sprinkler base advanced 120 degrees each time the irrigation line was turned on, the specific size of circle sector irrigated could be established independently with a separate mechanism. Irrigated sectors of 120 and 240 degrees were compared.

A randomly indexed-position sprinkler using curved grooves in the deflector to rotate the head was also developed, Figure 15. In addition to the two curved grooves, four straight grooves were machined in the rotor to provide intermediate and long range streams of effluent. Reference marks on the sprinkler were used to determine relative rotation between the base and the cap during each test run.

During the tests, comparisons were made of the relative penetrations or melt-through produced by the 120-degree indexing, the randomly indexing, and the non-indexing sprinklers. The snow pack surface appearance with increasing degree of penetration is shown in Figure 16. The distribution and penetration of the indexed-position part circle sprinkler were satisfactory, however, this type sprinkler was not acceptable because it failed to oscillate satisfactorily during freezing temperatures. The randomly indexed-position sprinkler operated and penetrated satisfactorily, but did not give as uniform a distribution pattern as desired.

Since all of the experimentally designed sprinklers were deficient in one respect or another for winter operation and the commercially available rotating sprinklers have permitted reasonable operation in the winter period, the presently operating winter system of approximately 60 acres is fitted with commercially available rotating sprinklers.

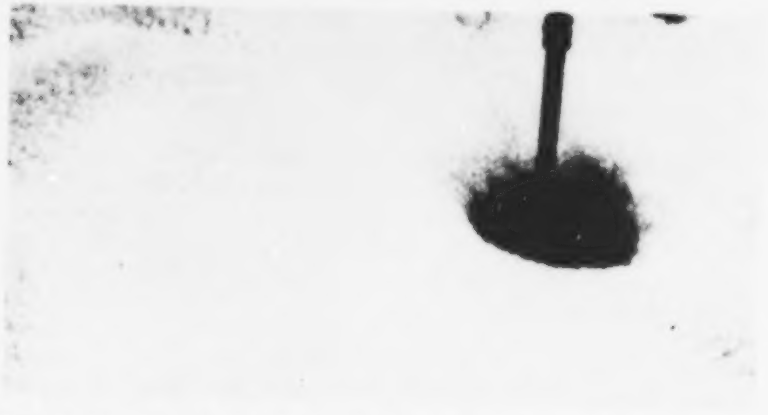
HYDROLOGIC CONSIDERATIONS

Three intensive and detailed hydrologic investigations were made in conjunction with this project. Two were conducted on the fine textured soil site in the Agronomy Area (14, 16), while the other was on a sandy soil site in the Gamelands Area (15).

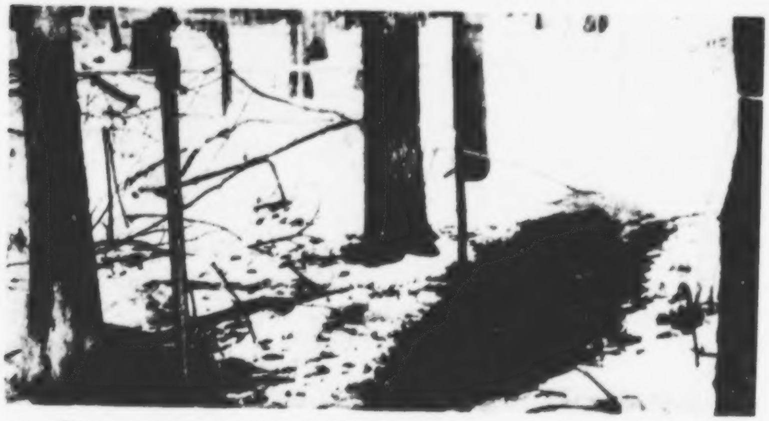
The 1965-67 Runoff Investigation

Site Description and Procedures. The first study (14) was conducted on the Reed Canarygrass Area. The soil on the area was a Hublersburg clay loam with a slope of 3 to 8 percent. The study area was subtended

a. Little Penetration (Note smooth ice layer)



b. Moderate Penetration (Note honeycombed effect)



c. Severe Penetration (Note complete melt-through)

Figure 16. Surface Appearance with Various Degrees of Penetration of Snow by Effluent Applied with Different Sprinklers.

by four lateral irrigation lines 800 feet long, with a staggered spacing of sprinklers, 80 x 80, which applied two inches of wastewater at weekly intervals. The application rate was ¼ inch per hour. Within this area approximately 2.4 acres contributed surface runoff to a 90-degree V-notch weir gauging station. The permanent groundwater table was approximately 200 feet below the soil surface in the bed rock.

At seven sites, (S1-S7) at approximately 100-foot intervals along the length of the slope, shallow wells (4-inch diameter perforated fiber pipe) were installed to a depth of four feet and piezometers (3/4 inch steel pipe) to depths of 2, 4, 6, 8 and ten feet. Piezometers are designated by site number and depth, e.g. S1-P10 indicates Site 1 and Piezometer at the 10-foot depth. Figures 17 and 18 show the topography of the site and a vertical profile through the piezometer sites.

To characterize the soil properties important to its hydrologic behavior infiltration rates were determined using a double ring infiltrometer method as described by Slater (17). Soil cores, 3 inches in diameter and 3 inches high were obtained at 6-inch increments to depths up to four feet. These cores were used to determine percolation rates, aeration porosity at 50 cm tension and bulk density of the various layers. In addition samples were collected at 6-inch intervals to a depth up to ten feet using a trailer mounted hydraulic sampler. These soil samples were used for mechanical analyses (18) and for pore size distribution measurements using a mecury intrusion porosimeter (19). In conjunction with the runoff data, water samples were taken periodically during periods of runoff at the weir to determine pH, chloride, phosphorus, nitrate and methylene blue active substance (MBAS) content. Determination procedures are described in Standard Methods (20), with the exception of the chloride concentration, which was determined by using an Aminco-Cotlove Chloride Titrator (21).

The results of the analyses of these samples were then compared with analyses of the applied effluent as well as analyses of samples taken at a depth of six inches, from a suction lysimeter installed at S4. Since phosphorus is almost completely removed by six inches of soil (8), its concentration was used in investigating the hypothesis that surface runoff occurring after the day of irrigation was actually a result of subsurface water flow and resulting downslope seepage.

Soil Properties. The results of infiltration determinations for S1-S7 are presented in Table 5 and represent an average of three replications. These results indicate that average infiltration rates exceed the effluent application rate of 0.25 inches per hour.

Percolation determinations made on collected core samples indicate the range of subsoil permeabilities at various depths and sites along the

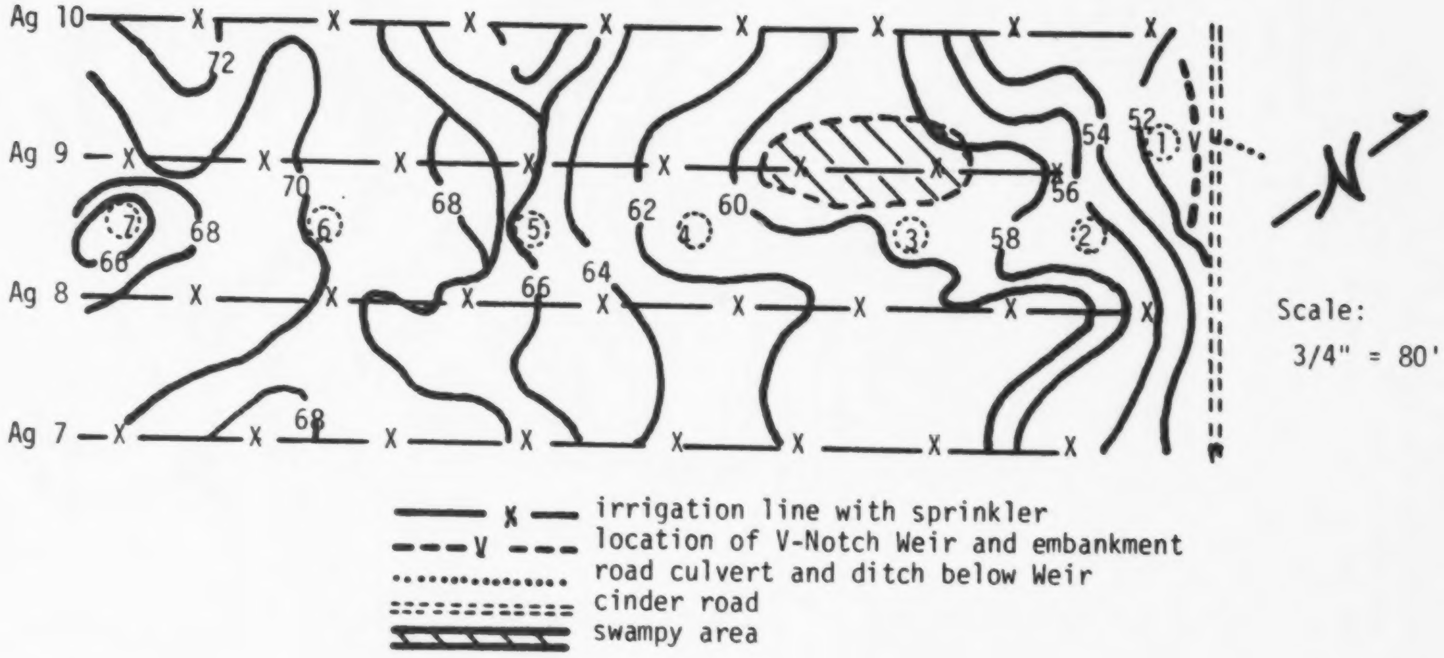

Ag 10
Ag 9
Ag 8
Ag 7
72
70
68
68
68
66
66
64
62
60
58
56
54
52
68
1
2
3
4
5
6
7
V
N
Scale:
3/4" = 80'
irrigation line with sprinkler
location of V-Notch Weir and embankment
road culvert and ditch below Weir
cinder road
swampy area

Figure 17. Topographic Map of Research Area with Location of Piezometer Sites, Irrigation Lines and V-Notch Weir.

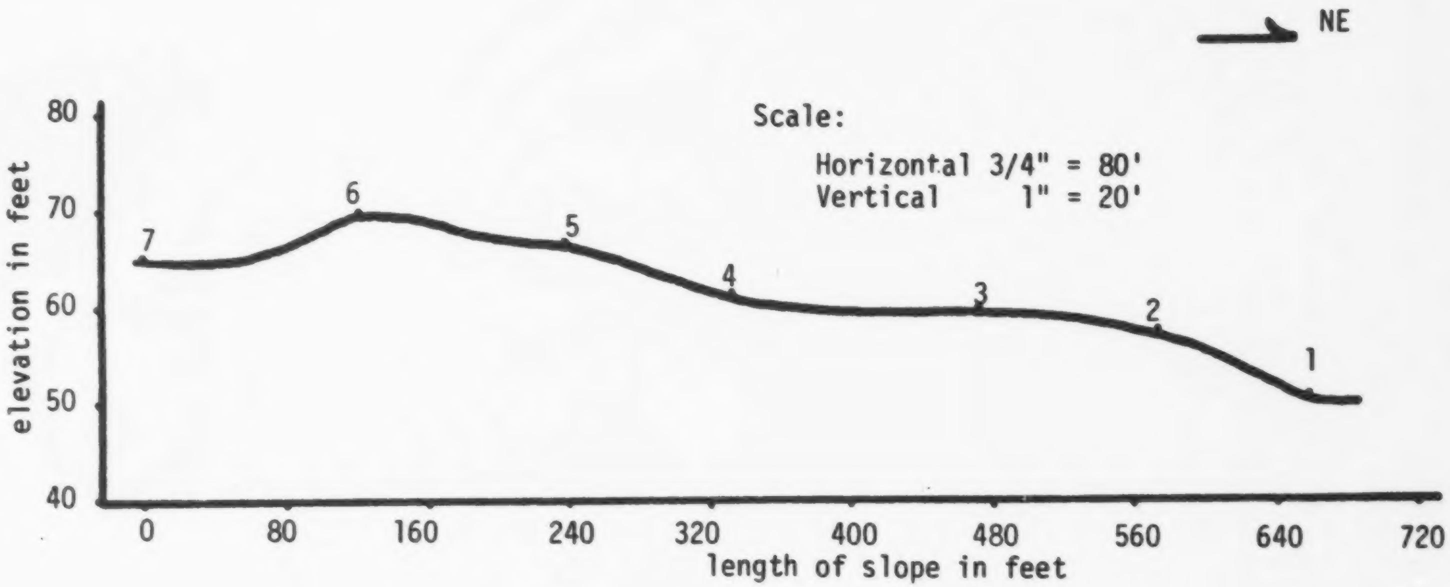


Figure 18. Profile Diagram of Hillside with Location of Piezometer Sites.

research hillside. These results are summarized in Table 6 and are an average of three replications.

Table 5. Average Infiltration Rates at Sites 1-7.

Site	Infiltration Rate
	Inches/hr
1	0.65
2	0.53
3	0.90
4	2.47
5	2.50
6	0.97
7	3.83

Table 6. Average Percolation Rates (inches per hour) at Six Inch Intervals to Depths Listed at Sites 1-7

Depth	1	2	3	4	5	6	7
0-3	29.60	10.92	2.74	12.59	0.94	7.80	1.90
6-9	1.19	3.82	1.85	1.79	0.32	2.80	1.35
12-15	1.85	0.76	0.08	0.48	1.36	1.27	0.28
18-21	0.62	1.98		0.38	0.75	0.51	0.23
24-27	0.50	0.42		0.95	0.47	0.22	0.00
30-33		1.01		0.49	0.10	0.05	0.00
36-39		0.02			0.70	0.16	0.00
42-45		0.04			0.07	0.00	0.03
48-51		0.13			0.20	0.09	
54-57		1.04					

These results indicate soil percolation rates ranging from 29.60 inches per hour to 0.00 inches per hour. There was an inverse relationship between depth and percolation rate as given by an r value of -0.359 which is significant at the one percent level.

Generally the percolation rates for the 0-3 inch cores exceeded the infiltration rates except at S5 and S7, but in all cases these rates exceeded the irrigation application rates. Only at depths greater than 12 inches did cores show percolation rates less than irrigation application rates (0.25 inches per hour). Percolation rates less than 0.25 inches per hour occurred at the 12-inch depth at S3, at the 18-inch depth at S7, at the 24-inch depth at S6, at the 30-inch depth at

S5 and at the 36-inch depth at S2. Percolation rates exceeded 0.25 inches per hour to a depth of at least 24 inches at S1 and at least 30 inches at S4.

The percentages of sand, silt and clay differ considerable at different sites and at different depths within each site. Percentages of sand range from 8-47%, silt 12-49%, and clay 21-72%. Textural class ranged from loam to clay loam to clay. These large ranges in the three size fractions indicate the variability present in the soil and help to explain the differences in permeabilities at different depths.

Aeration porosity as determined at 50 cm water tension from the core samples is summarized in Table 7. These values illustrate a range of aeration porosity from 1.3 to 16.1 percent. These values are generally quite low, especially at lower depths. Depth and aeration porosity were negatively correlated, with an r value of -0.429 which was highly significant.

Table 7. Average Aeration Porosity (Percent by Volume at 50 cm Water Tension at Six Inch Intervals to Depths Listed at Sites 1-7

Depth	1	2	3	4	5	6	7
0-3	15.5	9.1	14.5	11.0	13.3	14.6	7.3
6-9	15.4	9.6	16.1	8.6	9.0	10.2	11.0
12-15	16.1	8.0	10.5	8.9	13.6	10.1	8.4
18-21	13.1	10.5		13.8	11.5	6.0	5.7
24-27	7.9	9.2		12.8	10.5	7.5	1.3
30-33		13.2		14.8	8.9	5.7	1.5
36-39		9.5			7.1	7.8	3.7
42-45		12.1			3.6	3.6	6.3
48-51		8.9			7.8	5.2	
54-57		8.0					

A correlation analysis indicated a positive significant correlation of aeration porosity and percolation rates. However, the r^2 value of 0.05 indicates a considerable residual variation in percolation rate which may not be associated with aeration porosity.

Bulk densities were also determined for the soil cores and are presented in Table 8. These values ranged from 1.17 grams per cc to 1.70 grams per cc and showed highly significant correlations as follows: a positive r value for depth of 0.492, a negative r value for aeration porosity of -0.337, and a negative r value for percolation rates of -0.301.

Table 8. Bulk Density (grams per cc) at Six Inch Intervals To Depths Listed at Sites 1-7

Depth	1	2	3	4	5	6	7
0-3	1.37	1.47	1.36	1.26	1.30	1.45	1.32
6-9	1.38	1.53	1.43	1.41	1.31	1.66	1.32
12-15	1.30	1.56	1.57	1.53	1.40	1.60	1.37
18-21	1.17	1.54		1.62	1.52	1.68	1.49
24-27	1.36	1.50		1.64	1.56	1.65	1.61
30-33		1.54		1.70	1.62	1.58	1.53
36-39		1.52			1.66	1.43	1.52
42-45		1.58			1.66	1.50	1.58
48-51		1.54			1.66	1.50	
54-57		1.54					

Pore size distribution was determined in fragments from soil samples obtained by the hydraulic sampler and are expressed in Table 9 as the percentage of total porosity; porosity between 175 and 10 microns in diameter and; porosity between 10 and 0.10 microns. The larger pores best characterize the water relationship in terms of water movement and temporary storage within the soil. The smaller pores characterize the more permanent storage capacity.

The much smaller intra-fragment porosity in the size range 175 to 10 microns determined by the mercury intrusion procedure, when compared with the aeration porosity as determined in the cores, indicates that many of the larger pores (>60 microns) characterized by the 50 centimeter tension value are inter-fragment or inter-ped in character.

The percentages of total porosity in Table 9 were calculated from bulk density values determined for soil clods or peds used in the mercury intrusion porosimeter study. Since the inter-fragmental pore space was not measured and the fragments were oven dried, the porosimeter bulk densities are considerably higher than the core bulk densities and consequently result in lower total porosity values.

Hydrologic Measurements.

Shallow Wells. Measurements from the shallow wells definitely indicated the presence of perched water table conditions over the entire research area. Throughout the entire period, August 1965 - July 1967, the wells at S1, S3, S4 and S7 continuously showed free water levels within four feet of the soil surface. The well at S5 became dry only if irrigation was delayed for one or more weeks. The wells at S2 and

Table 9. Percentages of Total Porosity, Porosity from 175 to 10 Microns and from 10 to 0.10 Microns in Diameter for Sites 1-7 at the Given Depth Intervals

	Depth Intervals (inches)											
					Site 1							
Porosity Fraction	0	6	12	18	24	30	36	42	48	54	60	66
Total	40.5	41.2	51.4	36.7	34.4	29.9	32.1	34.4	37.0	31.0	32.5	30.6
175-10	4.3	5.4	9.1	4.4	1.2	1.8	0.9	1.9	0.7	1.0	1.5	1.5
10-.10	29.5	30.5	27.4	20.1	20.5	17.2	19.0	19.9	22.6	4.6	17.4	7.2
					Site 2							
Porosity Fraction	0	6	12	18	24	30	36	42	48	54	60	
Total	35.9	28.0	32.1	26.1	31.0	29.0	36.9	37.8	37.8	39.3	31.0	
175-10	5.2	3.1	3.4	1.9	1.8	3.2	0.8	0.7	1.0	0.7	1.3	
10-.10	20.0	16.6	11.5	12.7	6.8	9.3	6.0	5.3	5.3	4.7	9.0	
Porosity Fraction	66	72	78	84	90	96	102	108	114	120	126	
Total	31.0	34.0	35.5	32.5	33.2	30.2	31.0	31.7	32.1	32.1	32.1	
175-10	1.8	3.3	2.9	2.5	1.2	1.5	0.9	0.9	1.2	0.8	0.9	
10-.10	14.9	13.9	13.9	14.4	12.2	10.0	11.9	10.2	7.5	7.0	10.1	
					Site 3							
Porosity Fraction	0	6	12	18	24	30	36	42				
Total	43.8	40.8	38.5	28.7	30.6	29.5	28.7	29.1				
175-10	4.4	3.2	4.6	3.3	4.3	3.4	2.6	2.4				
10-.10	32.5	27.2	16.5	17.0	12.9	9.8	11.3	9.8				
Porosity Fraction	48	54	60	66	72	78	84					
Total	31.4	30.2	29.5	30.2	29.9	30.2	30.2					
175-10	2.3	1.9	1.6	3.0	2.9	2.9	0.7					
10-.10	10.1	9.4	12.1	10.6	13.2	11.2	11.1					

Table 9. (continued)

	Depth Intervals (inches)								
	Site 4								
Porosity Fraction	0	6	12	18	24	30	36	42	
Total	43.1	43.4	32.5	32.3	28.7	29.9	28.7	26.8	
175-10	2.6	2.7	1.6	2.3	2.7	1.1	1.0	1.2	
10-.10	34.1	32.8	11.5	6.0	5.2	3.9	12.7	8.8	
Porosity Fraction	48	54	60	66	72	78	84	90	
Total	31.0	24.6	28.7	31.0	30.6	36.9	35.1	35.9	
175-10	1.5	1.4	0.9	0.9	1.3	1.1	1.4	1.3	
10-.10	16.4	17.6	13.2	7.7	4.2	3.6	6.0	9.0	
	Site 5								
Porosity Fraction	0	6	12	18	24	30	36	42	48
Total	43.4	38.5	35.5	32.5	32.9	26.1	26.1	32.9	31.0
175-10	3.8	1.9	2.2	2.9	2.5	0.9	1.0	3.0	1.9
10-.10	31.7	27.7	18.2	14.4	16.9	4.9	5.5	8.7	5.4
	Site 6								
Porosity Fraction	0	6	12	18	24	30	36	42	48
Total	29.9	34.8	32.1	31.0	31.0	34.0	34.8	33.6	35.1
175-10	2.5	2.0	1.4	2.2	0.9	1.4	0.9	1.1	2.5
10-.10	14.6	7.9	7.5	14.1	5.4	5.8	4.7	4.3	8.9
Porosity Fraction	54	60	66	72	78	84	90	96	102
Total	29.9	35.5	33.6	38.5	37.0	37.0	34.8	32.9	35.1
175-10	0.9	0.4	0.8	0.4	0.5	0.5	0.5	0.4	1.1
10-.10	6.8	6.0	6.6	5.0	6.8	2.8	3.6	6.4	5.6

Table 9. (continued)

	Depth Intervals (inches)							
	Site 7							
Porosity Fraction	0	6	12	18	24	30	36	42
Total	40.0	37.8	41.2	29.5	29.5	28.4	27.2	30.6
175-10	3.1	4.3	2.2	0.7	3.8	0.7	1.3	0.7
10-.10	29.9	27.5	33.0	17.9	10.7	17.2	16.5	6.7
Porosity Fraction	48	54	60	66	72	78	84	
Total	29.5	30.2	28.7	30.2	29.2	31.7	34.0	
175-10	0.6	0.8	0.8	0.8	0.8	1.4	0.5	
10-.10	6.2	5.8	15.6	7.4	15.1	17.1	3.7	

S6 were the only ones which became dry within weekly irrigation intervals, and this occurred only during the summer and early fall.

Due to higher rates of evaporation and transpiration during the growing season, water levels in the wells were much lower than during the fall and winter. The typical responses of the shallow wells to irrigation are presented in Table 10. The 4/17 readings were taken immediately preceeding irrigation. The times of measurement of the values shown in Table 10, expressed as time in hours after termination of irrigation, are given in Table 11. As indicated, water levels approach the soil surface during and immediately after irrigation and then decline until rainfall or irrigation occurs again. These changes in water levels are illustrated in Figures 19 and 20.

Table 10. Shallow Well Elevations for Sites 1-7 on April 17-21, 1967

Date	1	2	3	4	5	6	7
4/17	48.14	52.62	57.68	58.39	61.48	DRY	62.07
4/18	50.80	56.15	59.18	60.35	63.95	66.73	64.49
4/19	50.53	55.46	58.87	60.15	64.54	66.00	63.73
4/20	50.05	54.27	58.18	59.79	63.78	65.84	62.91
4/21	47.79	53.57	58.01	59.55	63.28	DRY	62.53

Table 11. Time in Hours After Termination of Irrigation for Shallow Well Readings Presented in Table 10

Sites	4/18	4/19	4/20	4/21
1, 2	3	27	55	79
3, 4, 5, 6, 7	11	35	63	87

Field observations early in the summer of 1967 indicated that perched water table conditions may exist continuously at depths below the shallow wells. The conditions which lead to this conclusion were as follows. As a result of no effluent applications from June 5 to July 6, 1967 and a low rainfall total of 2 3/4 inches, all shallow wells became dry. This indicated that no perched water table existed at a depth of four feet below the soil surface. However after a two inch application on July 7, water levels were observed in all wells. Then after an additional application on July 10, surface runoff was

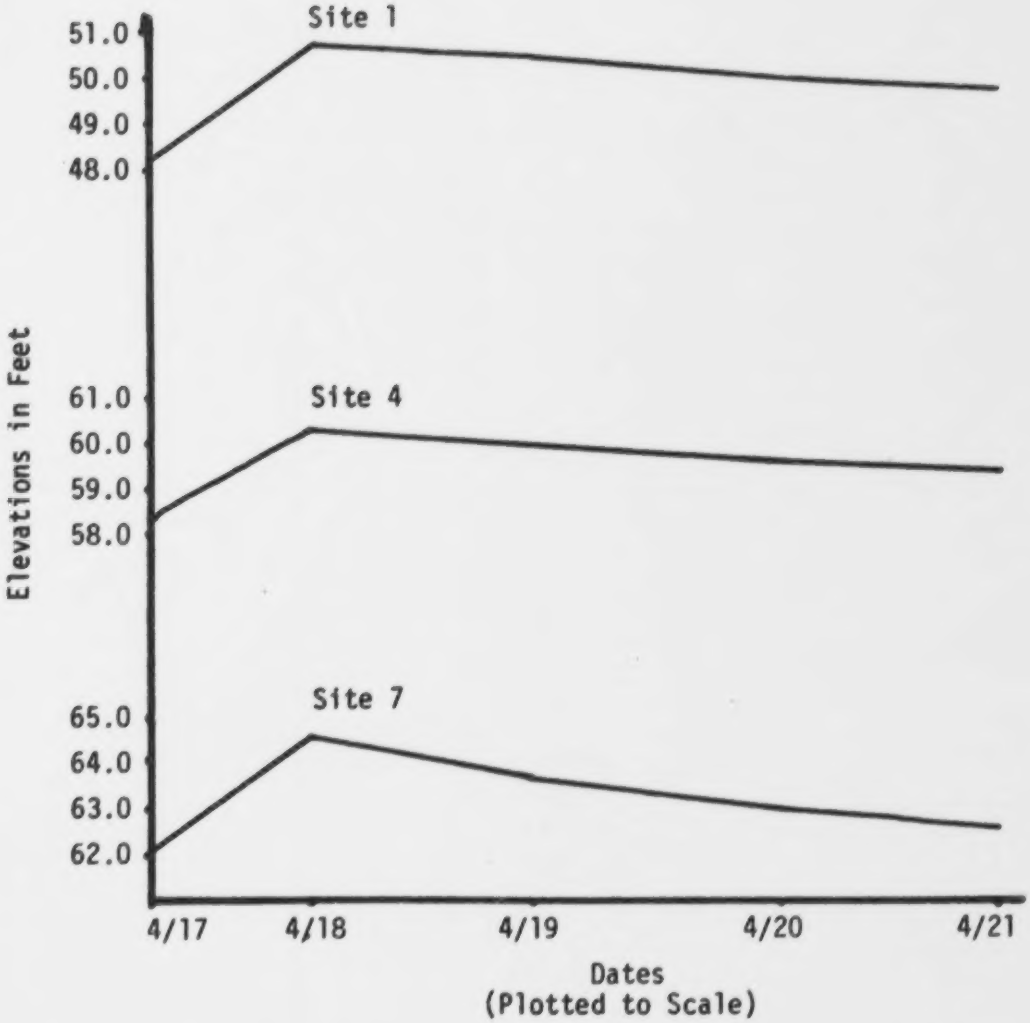


Figure 19. Shallow Well Water Level Elevations at Three Sites Showing Typical Responses to Irrigation on 4/17/67 with Two Inches of Sewage Effluent.

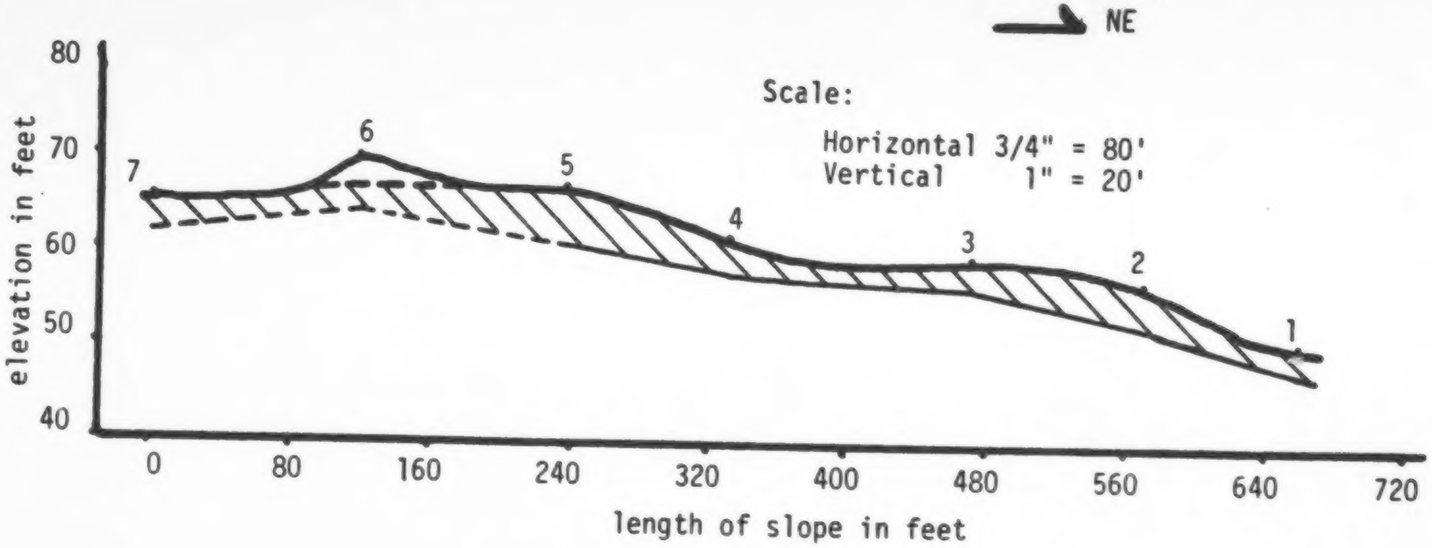


Figure 20. Cross Section of Hillside Showing Increase in Elevation of Perched Water Table (cross hatched area) 12 Hours After 2" Irrigation.

observed and all wells, with the exception of the well at S6, showed water levels at a height approximately equal to the ground surface. Only two possibilities exist to explain this situation. Either the perched water table persisted immediately below the depth of the shallow wells; or, the material slightly below the bottom of the wells is so impermeable that the perched water table is formed at this level.

A specific study of the actual change in water levels due to irrigation and rainfall was made to relate the well data to the nature of water movement on the hillside slope. The water level elevations for this study are presented in Table 12. The decline in the wells at the various sites was calculated as the difference between the elevations taken on July 18 at 8:00 a.m. (peak value) and on July 21 at 12:00 noon (final elevation).

Table 12. Water Level Elevations (feet) with Respect to Irrigation and Rainfall at Sites 1-7

	Date and Time					
Site	7/17 4 p.m.	7/18 8 a.m.	7/18 4 p.m.	7/19 4 p.m.	7/20 12 noon	7/21 12 noon
1	47.93	50.78	50.73	50.53	50.68	50.55
2	<52.65	56.37	56.14	55.57	55.54	54.81
3	57.90	59.14	59.12	59.01	59.13	58.99
4	59.36	60.34	60.29	60.22	60.38	60.32
5	61.87	65.11	65.03	64.66	64.73	64.26
6	<65.82	66.85	66.24	<65.82	65.83	<65.82
7	61.87	64.44	64.25	63.60	63.63	63.11

REMARKS:
1. Irrigation 7/17, 4 p.m. to 12 midnite for lines Ag 8 and 9; irrigation 7/18, 12 midnite to 8 a.m. for lines Ag 7 and 10.
2. .35 and .12 inches rainfall in a 24-hour interval before readings taken on 7/20 and 7/21, respectively.

Table 12 is summarized in Table 13 which lists the total decline for each well along with the order of magnitude of decline with one indicating the highest and seven the lowest. It was noted that the rates of decline are lowest in the areas of S1, S3, and S4 which indicates low permeabilities and/or seepage into these areas. Seepage into S1 probably originates from the area near S2. Seepage into S3 and S4 probably originates from the upslope area near S5 and S6. Calculations involving limiting permeability and capacity of the soil to store and transmit water were made for various sites using infiltration rates, percolation rates, and aeration porosity. As previously

Table 13. Total Declines in Water Levels of Shallow Wells in Feet and Order of Rapidity of Decline in Water Levels by Sites 1-7

	1	2	3	4	5	6	7
Total Decline	0.23	1.56	0.15	0.02	0.08	>1.03	1.33
Order of Decline	5	2	6	7	4	1[a]	3

[a] Other data were used which indicated that S6 showed the most rapid decline.

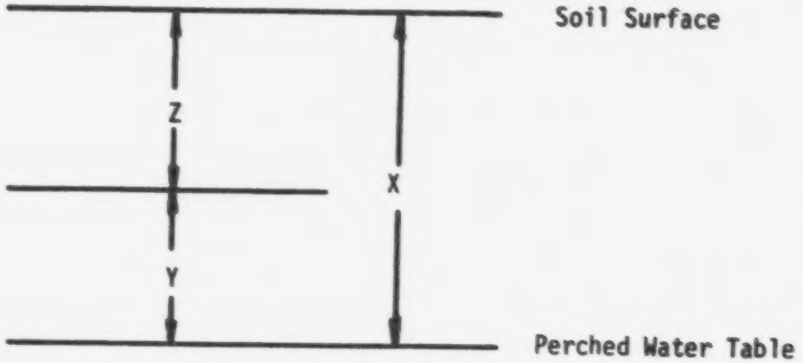
discussed, only at S3 is the soil percolation limiting; and, at no site is infiltration limiting the capacity of the soil to store and transmit the two inches of effluent irrigation.

The 50 centimeter aeration porosity value was used in determining the capacity of the soil to store water. Calculations indicated that if the water was drained from the soil pores at a tension of 50 centimeters (i.e., pores at least 50 cm above the perched or groundwater table) to a depth of two feet prior to irrigation that the capacity of this two-foot soil layer would be more than adequate to temporarily store the two-inch application of effluent.

Values for aeration porosity were available for six-inch increments to a depth of 54 inches at S2 and at the same increments to a depth of 30 inches at S4. These were used to calculate the actual deviations from the above situation in the field and are presented as examples in Table 14.

The water storage capacity of the soil, for specific perched water table conditions, was determined by measuring the distance from the soil surface to the surface of the perched water table before irrigation as illustrated in Figure 21. Assuming no water storing capacity in the soil at a distance less than 20 inches (50 cm) from the perched water table and storage capacity equal to the 50 centimeter tension aeration porosity at a distance greater than 20 inches above the perched water table, one can then compute the potential storage capacity. This can be related to the actual storage capacity as represented by the change in elevation of the perched water table induced by the two inch application of effluent.

The following examples of the above procedure were calculated for S2 and S4 using data presented in Table 14 and Figure 21. Since only



Where:

X = Distance from Perched water table to soil surface
Y = Cm tension for aeration porosity values (50 cm = 20")
Z = Thickness of soil under y cm tension (x - y)

Calculation:

	Site 2	Site 4
X	44"	24"
Y	20"	20"
Z	24"	4"

Storage capacity calculated for Z thickness from Table X

Site 2 = 2.24"
Site 4 = 0.44"

Figure 21. Calculation of Water Storing Capacity of the Soil Above the Perched Water Table for Sites 2 and 4.

Table 14. Aeration Porosity and Water Storage Values for Six-Inch Depth Increments in the Soils at Sites 2 and 4

Inches	50 cm Tension Aeration Porosity Site 2	50 cm Tension Aeration Porosity Site 4	Water Storage Site 2	Water Storage Site 4	Cumulative Water Storage Site 2	Cumulative Water Storage Site 4
	%	%	in.	in.	in.	in.
0-6	9.1	11.0	0.55	0.66	0.55	0.66
6-12	9.6	8.6	0.58	0.52	1.13	1.18
12-18	8.0	8.9	0.48	0.53	1.61	1.71
18-24	10.5	13.8	0.63	0.83	2.24	2.54
24-30	9.2	12.8	0.55	0.77	2.79	
30-36	13.2		0.79		3.58	
36-42	9.5		0.57		4.15	
42-48	12.1		0.73		4.88	
48-54	8.9		0.53		5.41	

two inches of effluent were applied either the aeration porosity overestimated the storage capacity or additional water was entering the site by runoff or seepage. At S4 a total of only 0.44 inches was needed to increase the elevation of the perched water table from a depth of 24 inches to the soil surface. As a result of this situation, where the water applied exceeded the water storage by approximately 1.5 inches, water is forced to flow downslope as surface runoff or as subsurface flow and resulting seepage or both. Therefore, it is obvious that S4 and the surrounding area, under these particular conditions, serves as a source of additional water to the lower portion of the hillside.

Piezometers. Piezometers were installed at two, four, six, eight, and ten foot depths at each of the seven sites. These installations measured hydraulic heads at various positions along the hillside. They were used in determining the direction of water movement at the sites and were also used in measuring permeability by the falling head method (22, 23). The permeabilities were measured on July 11, 1967, using the falling head method described by Kirkham (23). It should be noted that the procedures used are commonly based on the rate of seepage into the piezometer, but according to Kirkham, the same procedure is applicable to the falling head method, where a head is established within the pipe and recedes as water flows from the pipe. The following conditions must be fulfilled in order to use this method. The base of the piezometer must be below the water table and the water level in the piezometer must be at least 20 centimeters (8 inches) above the water table. These conditions were fulfilled at the time of measurement. After calculating the time (t_2 - t_1) and the ratio of the effective heads (h_1 / h_2), as given in the permeability equation (6) the permeabilities were read directly from a nomograph (6). These results are presented in Table 15.

These data indicate that 25 piezometers had permeabilities of less than 0.014 in. per hour. A comparison of these permeability values with the time of peak piezometer response to irrigation, shown in Figures 22-28 indicates that in all examples where the peak response was only 1 or 2 days after irrigation, the permeabilities were 0.70 inches per hour or greater. However, S7 - P_2 exhibited a permeability value of 1.13 inches per hour but did not reach a peak until the fourth day. This delay may be due to a delay in input of water from adjacent higher elevations.

A correlation was made between the permeability values in Table 15 and the various soil properties, as determined from the samples collected by the hydraulic soil sampler. The correlation coefficients are presented in Table 16.

Table 15. Soil Permeabilities Determined on July 11, 1967 by the Piezometric Method for All Piezometers at Sites 1-7

Piezometer	1	2	3	4	5	6	7
				Inches Per Hour			
P_{10}	a	1.42	a	0.07	a	a	a
P_8	a	a	a	a	a	a	a
P_6	a	2.83	a	a	a	a	a
P_4	4.25	0.01	a	a	a	0.70	a
P_2	2.83	a	0.04	0.71	a	a	1.13

[a] Values less than the lowest values on the nomograph (0.014 in./hour).

Table 16. Correlation Coefficients Relating Soil Permeability and Various Soil Properties

	Bulk Density	Large Pores	% Silt	% Clay
Permeability	-0.380	0.223	0.441*	-0.328

The correlation of percent silt with permeability was significant at the five percent level. Other correlation coefficients were nonsignificant. A negative correlation coefficient (-0.579) showing significance at the one percent level was found between the percentage

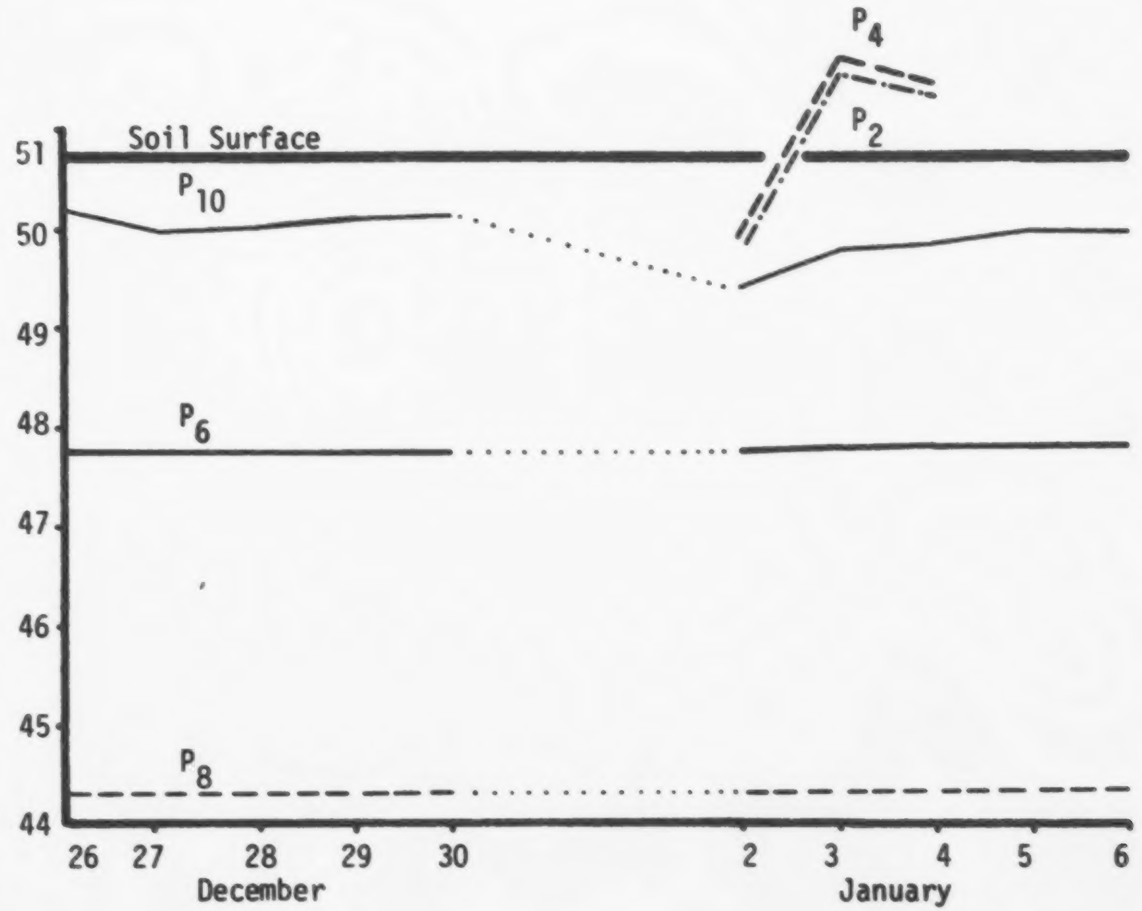


Figure 22. Water Level Elevations in Piezometers at Site 1 for Two Observation Intervals, 1966-67.

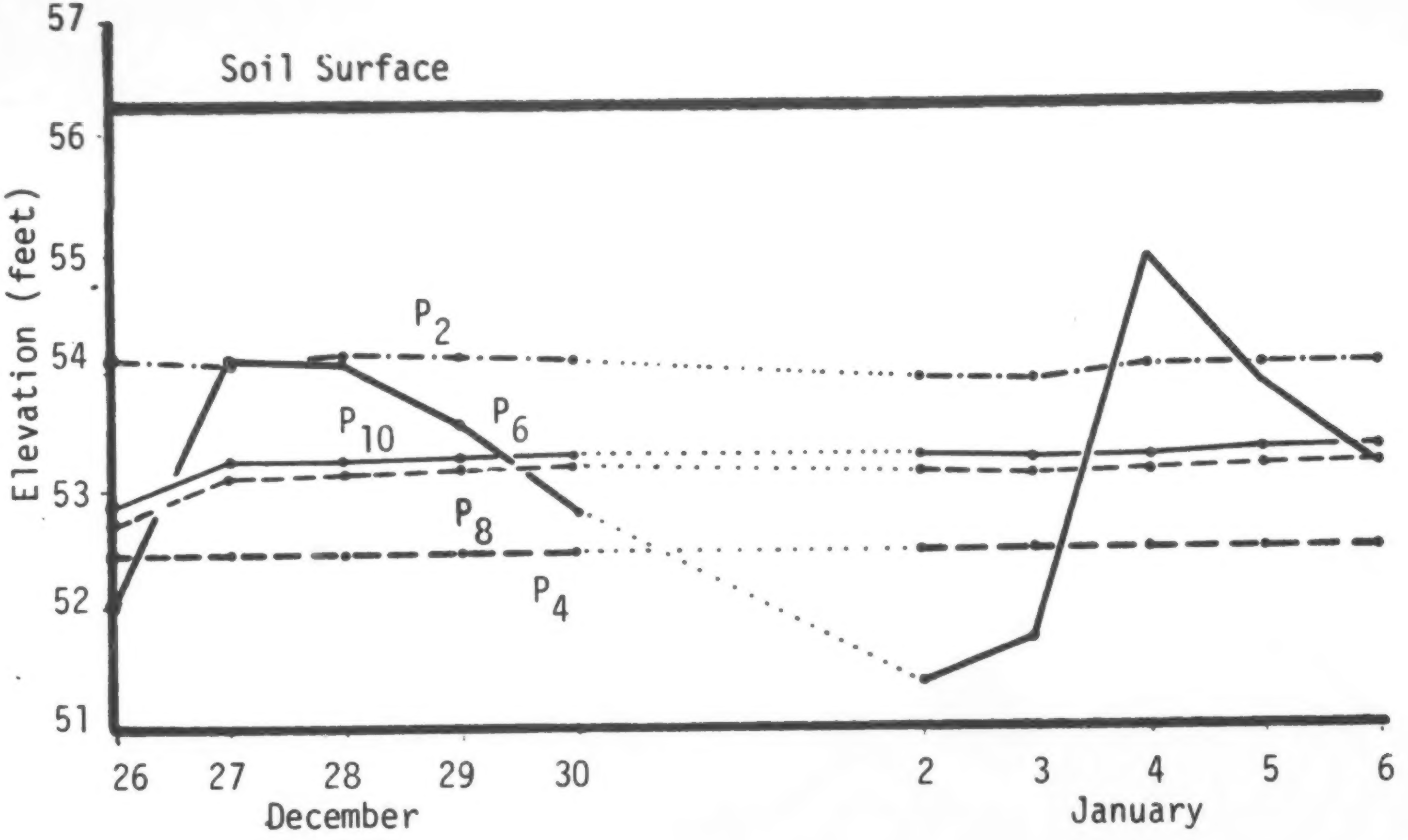


Figure 23. Water Level Elevations in Piezometers at Site 2 for Two Observation Intervals, 1966-67.

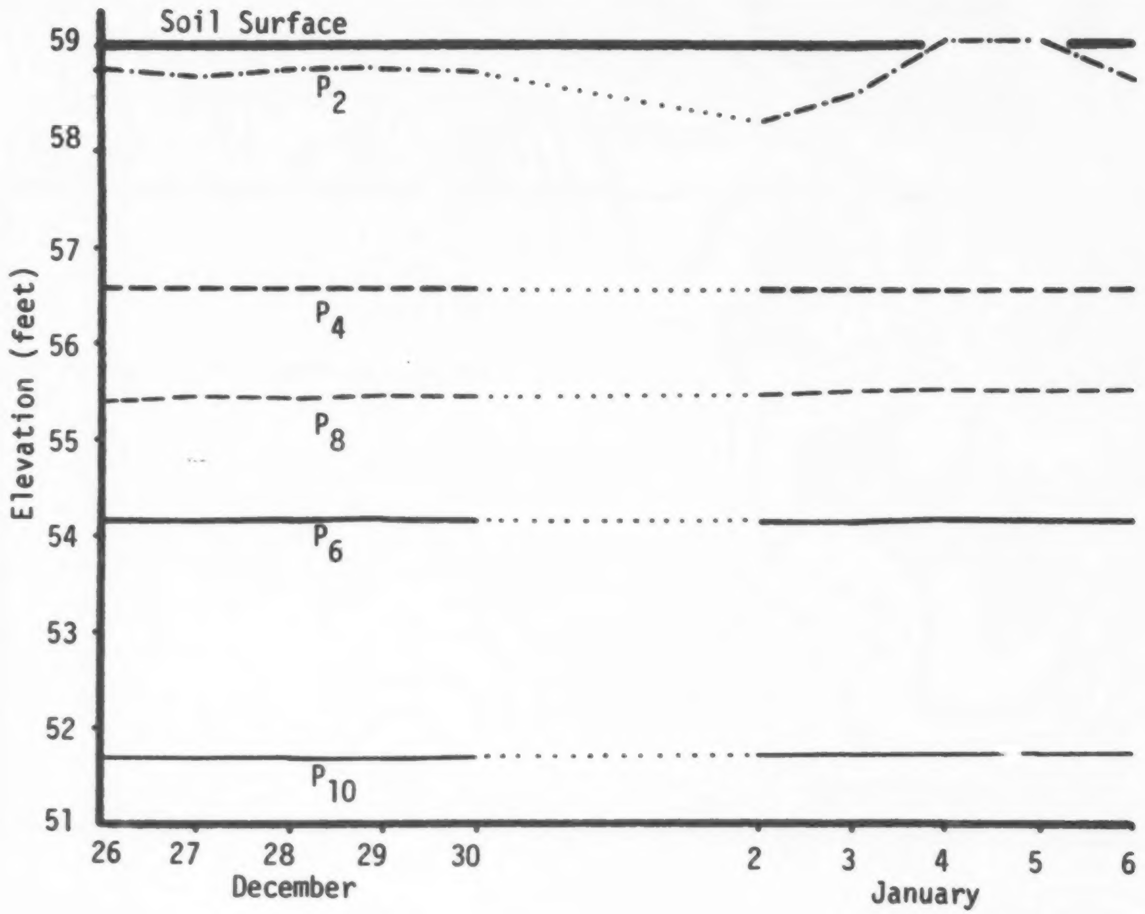


Figure 24. Water Level Elevations in Piezometers at Site 3 for Two Observation Intervals, 1966-67.

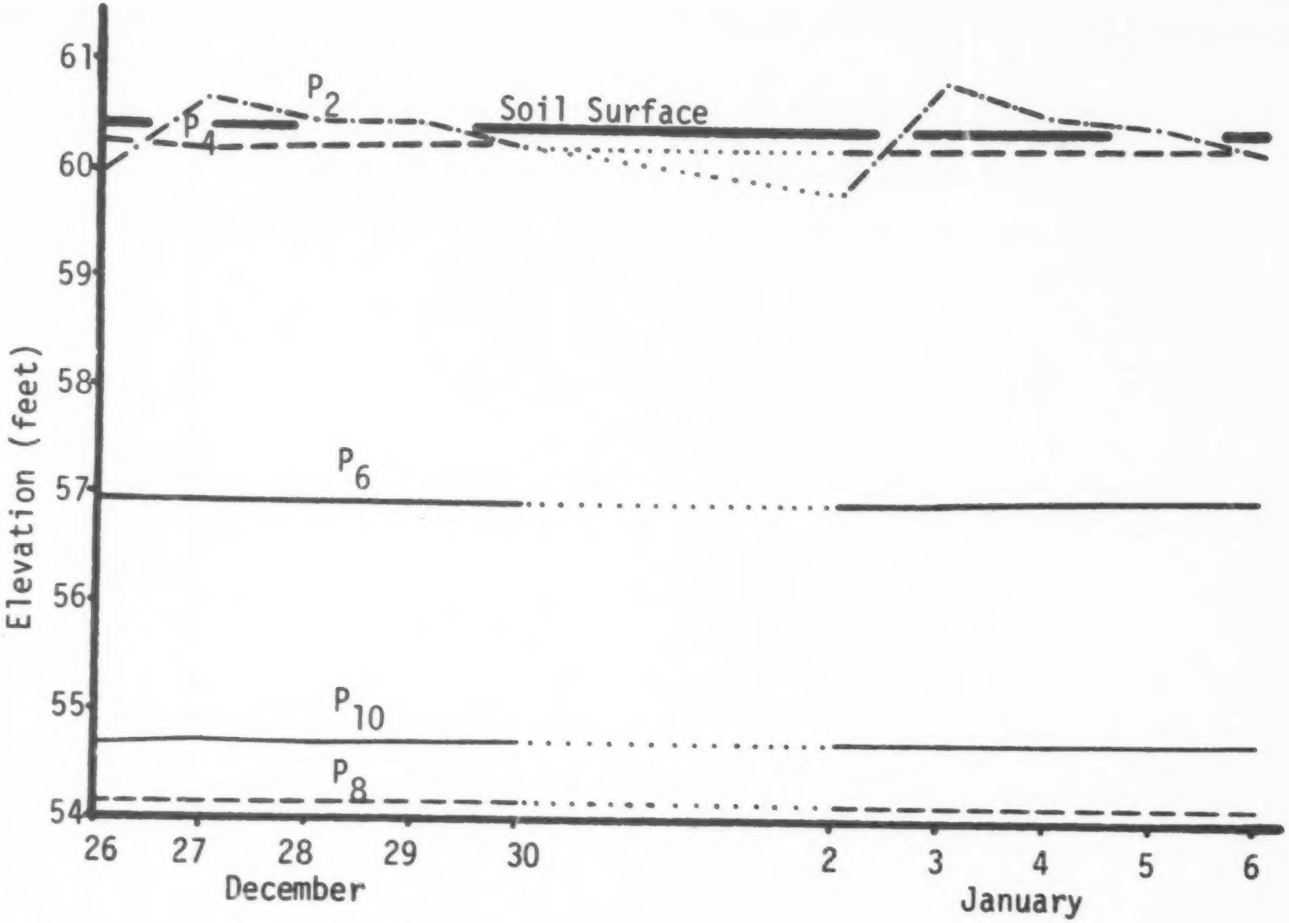


Figure 25. Water Level Elevations in Piezometers at Site 4 for Two Observation Intervals, 1966-67.

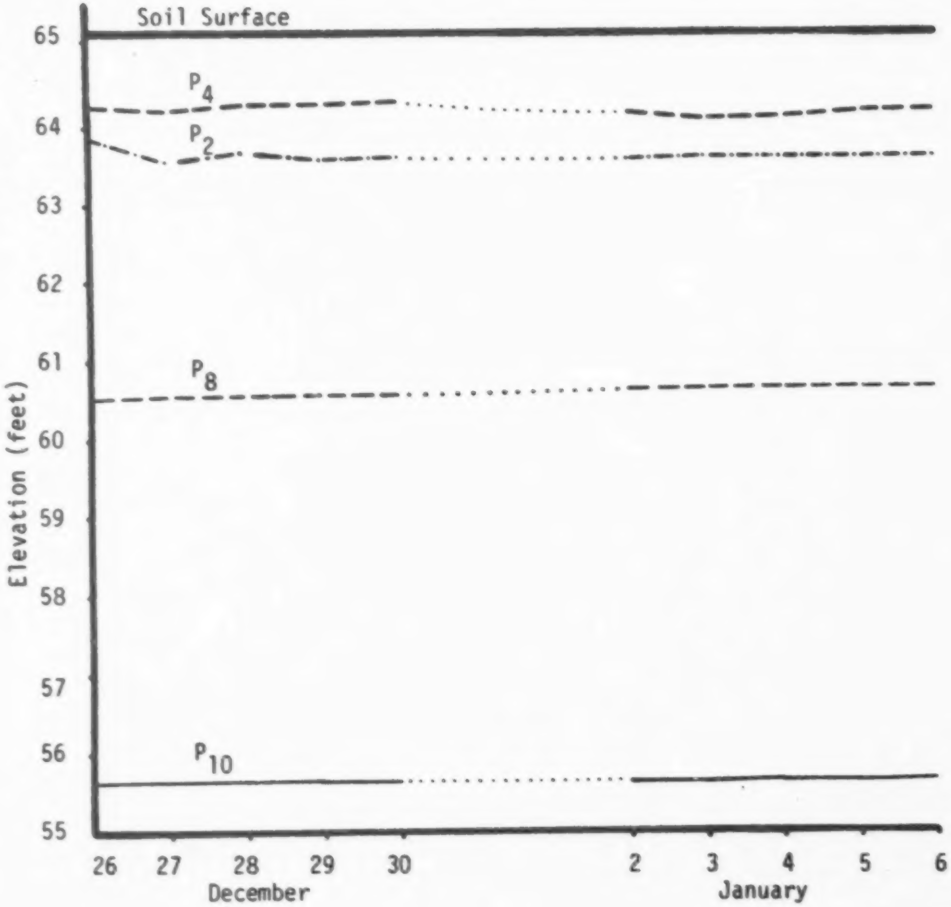


Figure 26. Water Level Elevations in Piezometers at Site 5 for Two Observation Intervals, 1966-67.

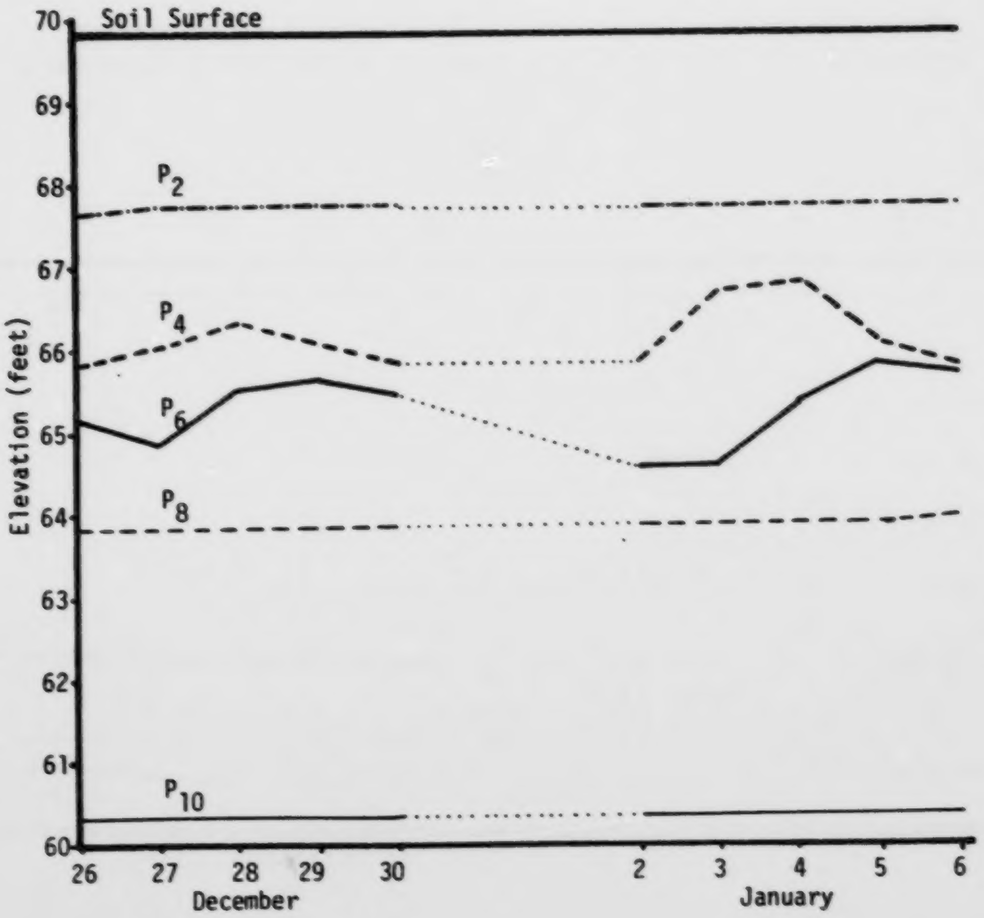


Figure 27. Water Level Elevations in Piezometers at Site 6 for Two Observation Intervals, 1966-67.

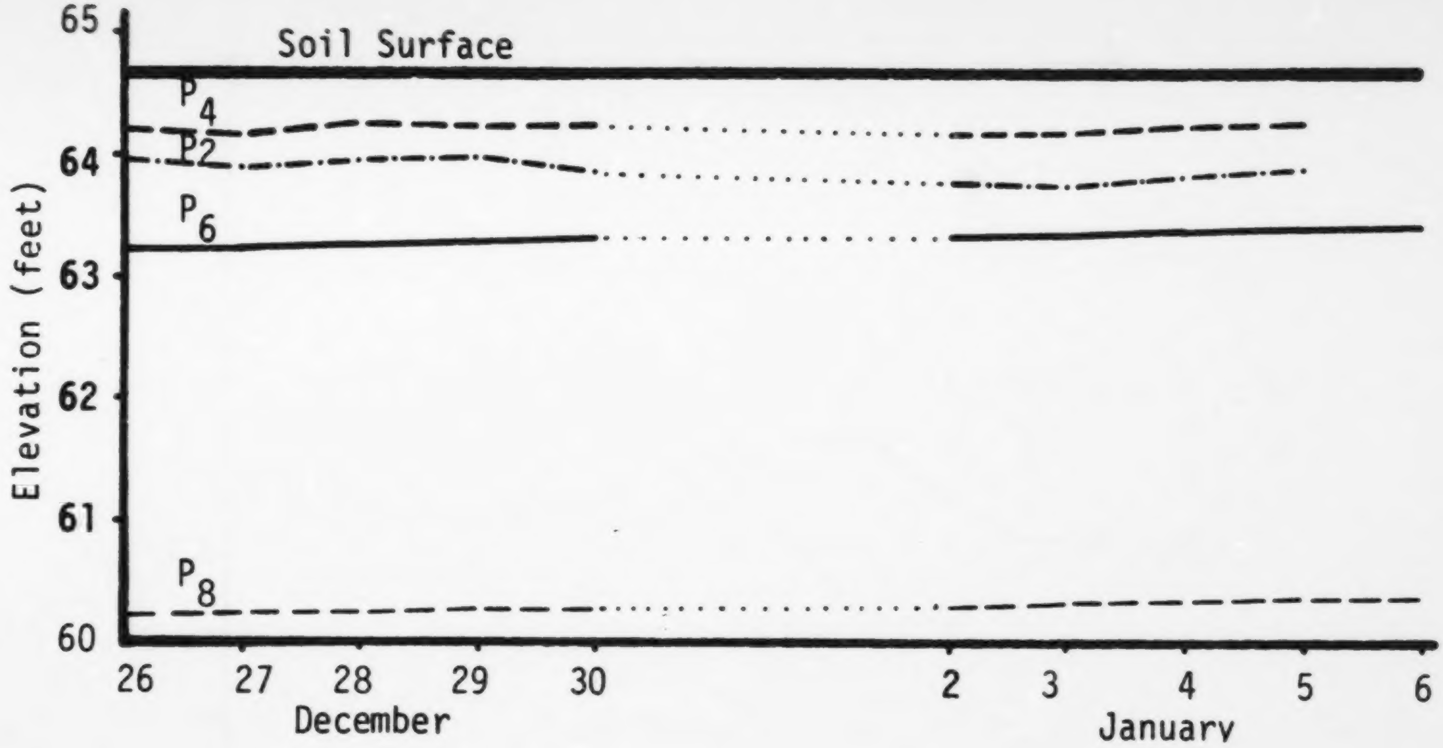


Figure 28. Water Level Elevations in Piezometers at Site 7 for Two Observation Intervals, 1966-67.

of clay and large pores. Correlation coefficients significant at the five percent level were found between percent sand and large pores (0.494), between clay and bulk density (-0.465), and between large pores and depth (-0.506). The nature and direction of subsurface water movement with respect to the soil surface and the perched water table will be interpreted from the water level elevations for January 1-6, 1967 (see Table 17). These data represent the study area during a period of high moisture content. The direction of water movement at the base of each piezometer was determined from the head difference in adjacent piezometers and is represented by arrows at each site in Figures 29-32. The permeabilities indicated in these figures were classified according to the following criteria:

1. Any zone with a piezometer permeability value greater than 0.014 inches per hour, was considered permeable and was indicated by the respective piezometer permeability value.

2. Zones with piezometer permeability values less than 0.014 inches per hour were subdivided as follows:

   a. Impermeable - zones with piezometer water level changes of less than 0.05 foot per 100 hours.

   b. Low permeability - zones with piezometer water level changes greater than 0.05 but less than 1.00 foot per 100 hours.

   c. Permeable - zones with piezometer water level changes greater than 1.00 foot per 100 hours.

The category 2c designates some of the piezometers with permeabilities less than 0.014 inches per hour by the Kirkham falling head method as being permeable due to large changes in hydraulic head during the 100 hour period.

Table 17. Peak Water Level Elevations for Shallow Wells and Piezometers for the Interval 1/2 - 1/6/67 at Sites 1-7

Measuring Device	1	2	3	4	5	6	7
P_{10}	50.00	53.36	51.74	54.77	56.67	60.39	a
P_8	44.37	53.26	55.54	54.19	60.67	63.99	60.33
P_6	47.82	54.99	54.18	57.00	a	65.81	63.40
P_4	51.74	52.52	56.58	60.28	64.18	66.81	64.23
P_2	51.56	54.12	59.19	60.86	64.01	67.72	63.87
Well	51.42	56.03	59.24	60.77	65.20	67.42	65.06

[a] No data available.

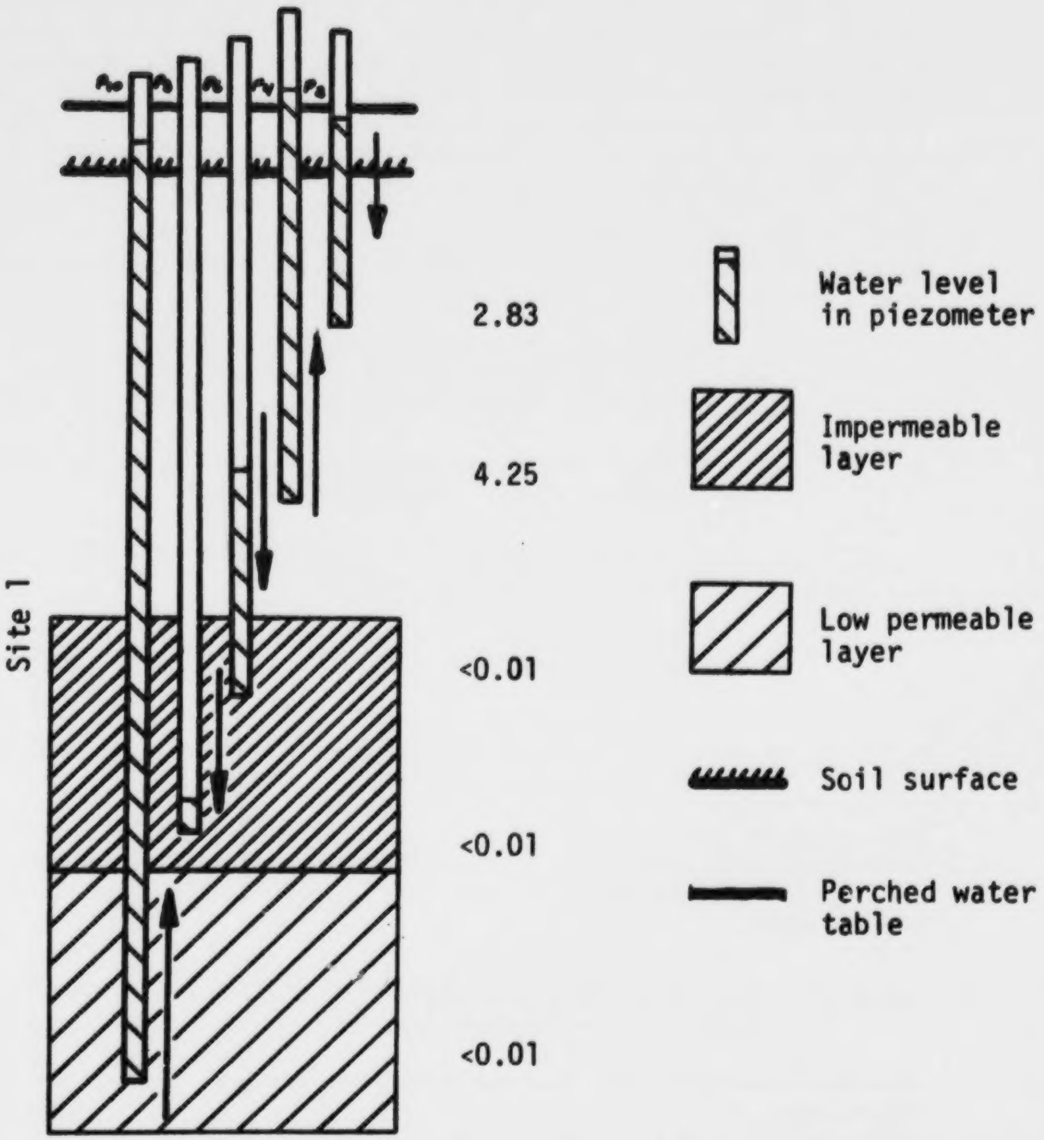

P10
P8
P6
P4
P2
Site 1
2.83
4.25
<0.01
<0.01
<0.01
Water level in piezometer
Impermeable layer
Low permeable layer
Soil surface
Perched water table

Figure 29. Set of Piezometers at Site 1 Showing Limiting Permeability, Perched Water Table, Water Levels in Piezometers and Predicted Directions of Movement.

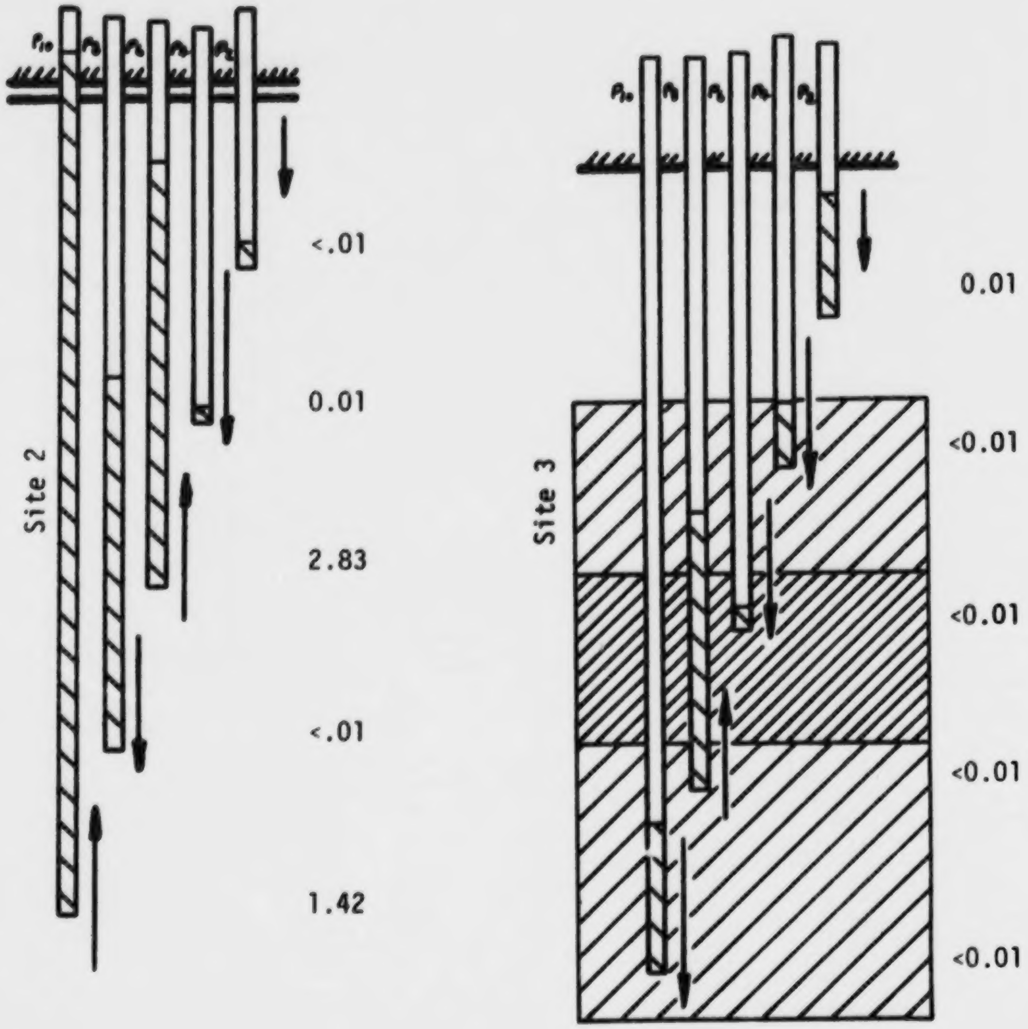

P_{10}
P_8
P_6
P_4
P_2
Site 2
<.01
0.01
2.83
<.01
1.42
P_{10}
P_8
P_6
P_4
P_2
Site 3
0.01
<0.01
<0.01
<0.01
<0.01

Figure 30. Same as Figure 29 but at Sites 2 and 3.

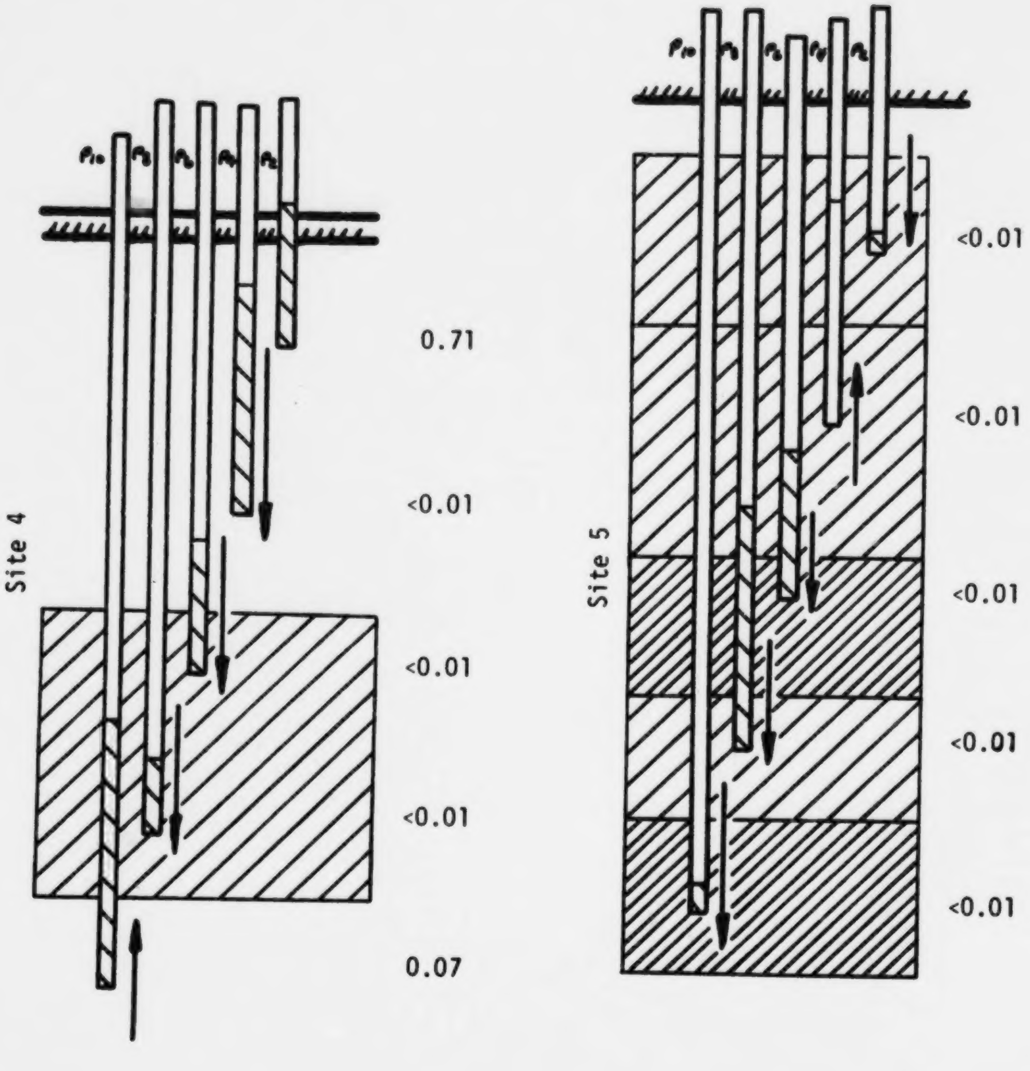

Site 4
P10
P8
P6
P4
P2
0.71
<0.01
<0.01
<0.01
0.07
Site 5
P10
P8
P6
P4
P2
<0.01
<0.01
<0.01
<0.01
<0.01

Figure 31. Same as Figure 29 but at Sites 4 and 5.

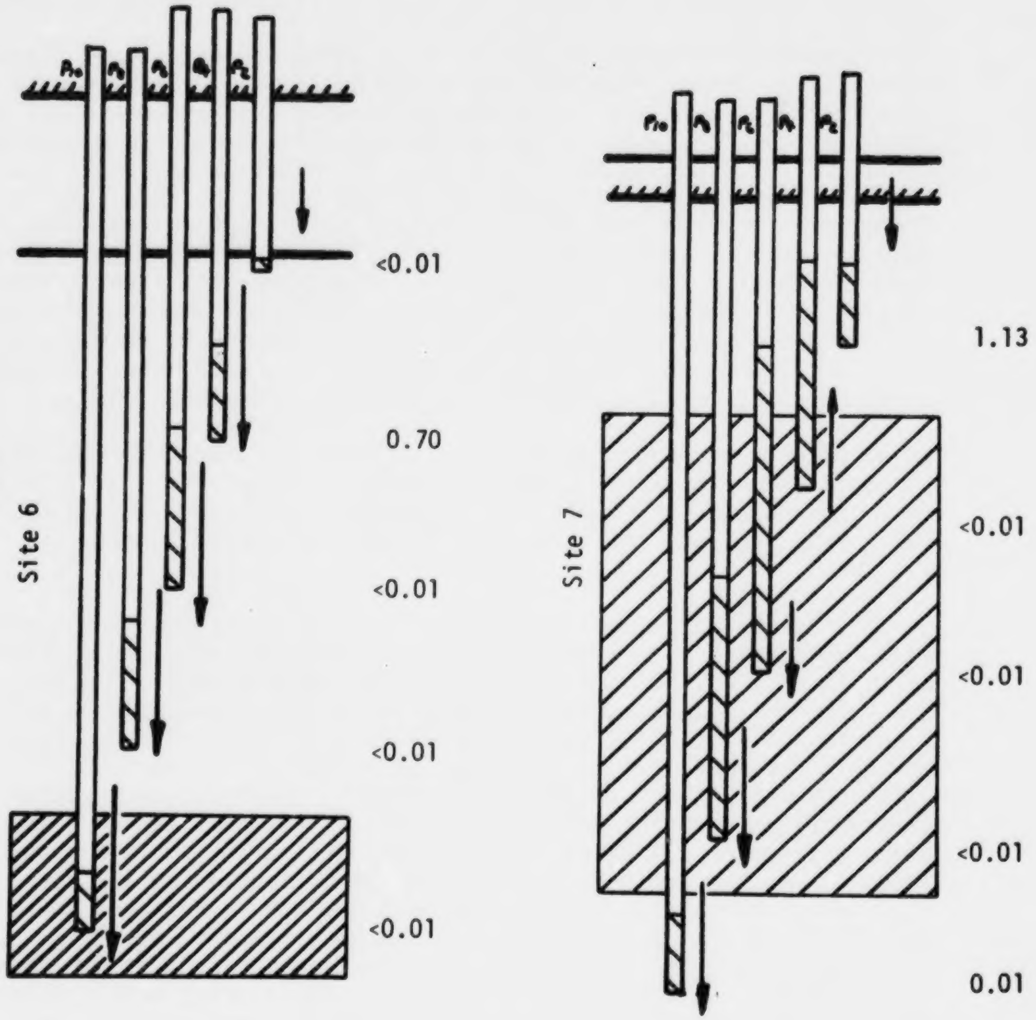

P_{10}
P_8
P_6
P_4
P_2
<0.01
0.70
<0.01
<0.01
<0.01
Site 6
P_{10}
P_8
P_6
P_4
P_2
1.13
<0.01
<0.01
<0.01
0.01
Site 7

Figure 32. Same as Figure 29 but at Sites 6 and 7.

On the basis of the head difference in adjacent piezometers it was found that artesian pressures were present in one or more zones at each site except S6 which topographically represented the highest elevation on the slope. Depths where these artesian pressures were indicated are as follows: S1 - two and ten feet, S2 - six and ten feet, S3 - eight feet, S4 - ten feet, S5 - four feet, S7 - four feet. All other directions of water movement were downward with the exception of S1 and S4 at the upper two feet where movement was horizontal.

In evaluating these directions of water movement, at several sites where strong trends were not indicated, additional data were used to more fully characterize the situation. These data are presented as graphs in Figure 33 and represent the two and four foot piezometers at sites 1, 5, and 7. At S1 in Figure 33, water levels in P_4 are slightly higher than, are equal to, or are less than levels in P_2. These levels, taken from data for August 15 to September 9, 1966, indicate that at various times water was moving horizontally, downward, or upward. For S5 in Figure 33, data show that water levels in P_2 are always higher than levels in P_4. This indicates that water movement is downward. For S7, data indicate an upward movement of water for the period December 5 to December 23, 1966. This is indicated by water levels in P_4 which are higher than those in P_2.

These changes in direction of water movement in the upper four feet of the soil are a result of changes in head at these levels. Since these heads can change more readily in this upper zone, as a result of rainfall or irrigation, the direction of water movement can also be altered.

Surface Runoff and Related Measurements. A final phase of the hydrologic measurements included the determination of rates and magnitude of surface runoff, factors affecting these measurements, and the analysis of runoff samples. Surface runoff was measured by a 90° V-notch weir previously described. Data were difficult to obtain during the winter, due to freezing conditions at the weir and in the stilling basin at the water level recorder. Peak discharge rates were determined during the operation of irrigation lines Ag 8 and 9 using a value of 1.8 acres as the area contributing to this runoff rate. The value for total runoff and the percentage of the total applied is calculated for the area of 2.4 acres. This area contributed water to the measuring station and was irrigated by irrigation lines Ag 7, 8, 9 and 10. Table 18 summarizes the runoff data secured from December 12, 1966 to July 11, 1967. The missing weekly intervals were due to freezing conditions, equipment failure, and intervals when irrigation was not carried on prior to and during a harvest period.

The above runoff data indicated a wide range in the amounts of total runoff. The range in this table is from 100 percent (54,230 gallons per acre) to 11 percent (6,168 gallons per acre). Also, irrigation

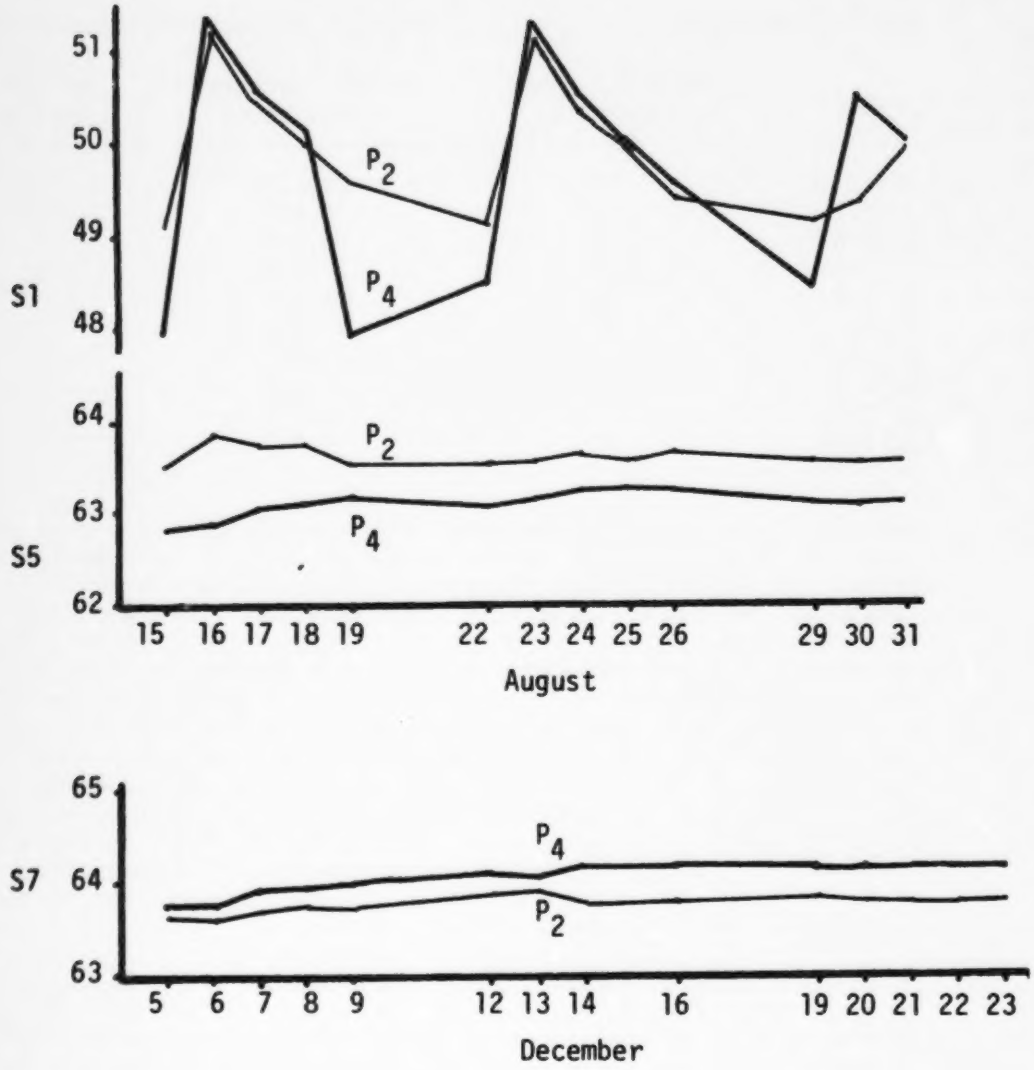


Figure 33. Piezometer Water Level Elevations (feet) at Several Sites in 1966.

Table 18. Surface Runoff Expressed as Peak Discharge (gpm per acre), Total Discharge (gal./acre), and Percent of the Total Application for the Indicated Dates.

Date	Peak Discharge (gpm/acre)	Total Discharge (gal./acre)	Percent of Total Applied
12/12/66	76	24,120	44
1/3/67	100	28,425	52
1/10/67	111	33,720	62
1/24/67	111	27,832	51
3/24/67	111	54,230	100
3/28/67	81	42,202	78
5/15/67	72	28,506	52
5/22/67	39	6,168	11
5/29/67	56	16,678	31
7/11/67	31	14,031	26

periods free from runoff have been observed during most of the growing season when much water was being lost from the soil by evapotranspiration. The highest values for runoff occurred when the soil was frozen and air temperatures were above freezing. When air temperatures were below freezing, the effluent could freeze on the soil surface in amounts which could considerably reduce the amount of total runoff. When air temperatures were higher than approximately 35°F, the effluent could not freeze but also could not infiltrate into the frozen soil. Therefore, under these conditions amounts of total runoff were high. Also, if air temperatures were quite warm, existing snow and ice on the soil melted and contributed additional water to the total runoff. Generally throughout the months when no frost or freezing was observed, the quantity of runoff was primarily influenced by the amount of rainfall and the water utilized by the reed canarygrass, as well as that lost by evaporation directly by the soil.

In conjunction with surface runoff measurements, soil temperature readings were taken during the fall and winter of 1966-67. This was done in part to determine: time and extent of frost and its effect on infiltration and surface runoff; and also to determine the effects of effluent applications on soil temperatures. These effects are exemplified by three specific examples which compare air temperature, soil temperature and soil frost conditions prior to and after irrigation. The resulting soil temperature and soil frost condition were related to the total runoff. In all examples, the temperature of the effluent as it left the sprinkler was 40-45°F. On December 12, 1966 (A) the weather had been warm prior to irrigation. No frost layers were present in the soil. On December 5, 1966 (B) the weather had been cold prior to irrigation and a frost layer was present at all sites before irrigation. After irrigation the frost layer had melted at S5 - S7, but was still present at sites 1-4. The temperature on the day of irrigation ranged from 26-33°. On December 26, 1966 (C) the weather had been and was below freezing before, during, and after irrigation. Soil frost and surface ice and snow were present before and after irrigation. Table 19 summarizes the effects of irrigation on soil temperatures in these examples. It is indicated from these examples that various situations with respect to these involved factors can occur, and no one broad generalization can be made. These results show that in A with warm soil conditions and freezing temperatures the day of irrigation, the soil temperatures decrease considerably. In B with a frost layer present and temperatures near 32°F, soil temperatures increased near the surface (within the first eight inches) but decreased below this level. In C with below freezing temperatures before, during, and after irrigation little infiltration occurred and as a result soil temperatures remained nearly constant.

Table 19. Soil Temperatures Averaged for 7 Sites at Various Depths Before and After Irrigation for Examples A, B, and C

Depth (inches)	A		B				C	
	Before	After	Before		After		Before	After
	S1-S7	S1-S7	S1-S4	S5-S7	S1-S4	S5-S7	S1-S7	S1-S7
2	39.9	36.0	32.9	32.7	34.0	36.2	32.9	32.8
4	39.2	36.4	33.9	35.2	34.2	35.0	33.9	33.6
8	39.9	37.3	35.2	35.8	35.4	36.3	34.8	34.8
12	41.1	38.5	37.2	37.8	36.5	37.3	35.9	35.7
18	42.6	40.1	39.1	40.0	38.0	38.0	37.4	37.1

Data relating runoff, air temperature, and frost conditions for 12/12/66, 1/3/67 and 1/24/67 are summarized in Table 20. The air temperature represents the maximum and minimum on the day of irrigation. The runoff is expressed as a percentage of the total applied.

The temperature range and field conditions for December 12 and January 3 indicate that a fairly high percentage of the effluent must have frozen during and shortly after application. Since a frost layer existed before and after irrigation on January 3, infiltration would have been very low but the runoff percentage was only 52%. Therefore under conditions favorable for freezing of the applied effluent, the magnitude of runoff was considerably reduced or at least delayed until

Table 20. Effects of Air Temperature and Soil Frost Conditions on Surface Runoff for Three Irrigation Applications

Date	% Runoff	Frost Layer Before Irrigation	 After Irrigation	Air Temp (°F.) min	 max
12/12	44	Absent	Absent	16	27
1/3	52	Present	Present	25	40
1/24	51	Present	Absent	48	64

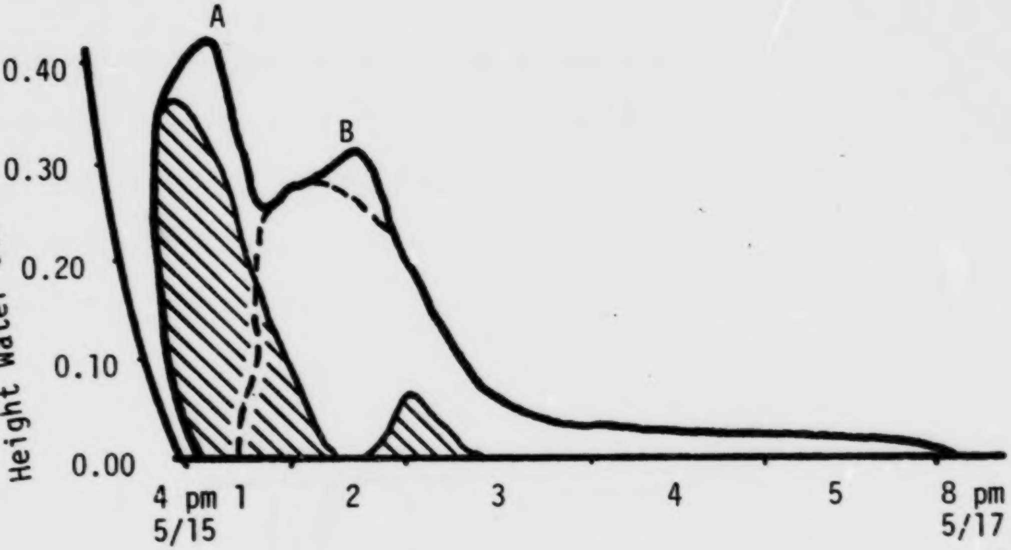
melting occurred. Also the melting of previously frozen applications of effluent may result in an apparent total runoff percentage of greater than 100. This situation must be considered, if capacities of structures designed to handle runoff are being considered in a winter irrigation system.

The duration of apparent surface runoff is extremely interesting in this investigation. Runoff has been recorded as long as 3 days after irrigation ceased in many instances, with no intervention of rainfall. Table 21 lists several examples of this prolonged runoff during which a measurable height of water was flowing over the V-notch weir.

Table 21. Total Duration of Runoff from 2-Inch Irrigation and Duration After Termination of Irrigation

Irrigation Dates	Duration of Runoff Total	 Hours After Termination of Irrigation
5/15	51	35
5/22	33	22
5/27	36	23

This long duration of runoff indicates that subsurface flow is a part of the total runoff. This idea was substantiated by studying two of the composite hydrographs presented in Figures 34 and 35. This was accomplished by estimating the surface runoff component from characteristics of the composite curve, and by extrapolating the declining limb. Next, by subtraction, the subsurface component was defined. Calculations for these two examples on May 22, and May 29, show that 75 and 63 percent respectively, of the total measured runoff consisted of



1 - 8 hour irrigation by Ag 8 and 9 with peak A

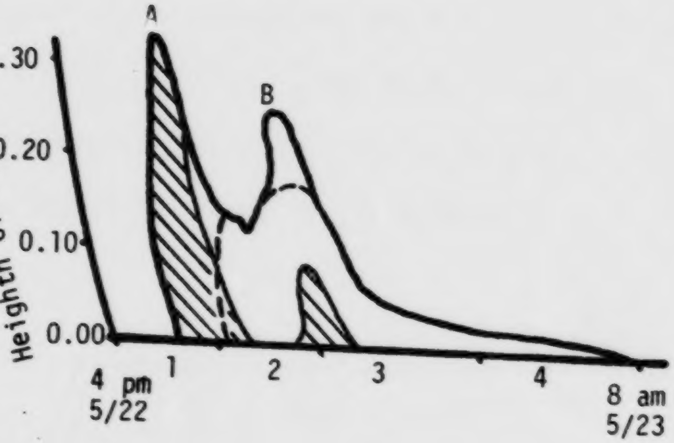
2 - 8 hour irrigation by Ag 7 and 10 with peak B

3, 4, 5 - successive 12 hour periods after irrigation

Shaded area represents extrapolated surface runoff curve

Area under dashed line represents subsurface flow

Figure 34. Runoff Hydrograph for Interval Beginning on May 15, 1967.



1 - 8 hour irrigation by Ag 8 and 9 with peak A

2 - 8 hour irrigation by Ag 7 and 10 with peak B

3, 4 - successive 12 hour periods after irrigation

Shaded area represents extrapolated surface runoff curve

Area under dashed line represents subsurface flow

Figure 35. Runoff Hydrograph for Interval Beginning on May 23, 1967.

subsurface water flow. These values indicate that a large portion of the total runoff can be attributed to subsurface water movement and seepage.

If the contribution of subsurface flow is large, the phosphorus content should decrease, as the percentage of surface runoff decreases and the percentage of subsurface flow increases, until all the runoff is subsurface in origin. Data obtained during the period January 31 to February 2, 1967 were used in determining the phosphorus concentrations of samples taken at various time intervals during the period of runoff. The concentrations of phosphorus in the effluent and the 6 inch suction lysimeter, at site 4, were taken from data of January 26. These results are summarized in Table 22 and support the theory that runoff consists of large amounts of subsurface seepage and lateral water movement.

The hydrologic conditions of the research area are summarized in Figure 36. This figure indicates the areas where apparent seepage has caused wet surface conditions on the second day after irrigation. These wet conditions relate the effects of perched water conditions and subsurface water movement to the observed surface wetness.

Table 22. Phosphorus Content in Applied Effluent, in a 6 In. Suction Lysimeter, and in Total Runoff at Different Times Expressed as Hours After Irrigation Had Terminated

Description of Sample	P Content (Mg/liter)
Pure Effluent	11.425
Suction Lysimeter	0.094
6 hours (runoff)	8.750
9 hours (runoff)	6.525
24 hours (runoff)	3.925
33 hours (runoff)	2.275
48 hours (runoff)	1.275
57 hours (runoff)	1.275

As a result of the application of two inches of sewage effluent per week, the previously existing drainage pattern was altered. Because of heterogeneous soil conditions consisting of irregular clay layers of low permeability, perched water conditions resulted.

The presence of these perched water conditions near the surface was responsible for a reduction in the ability of the soil to temporarily store or transmit water. This capacity for water storage and transmission had been so greatly reduced, especially during wet seasons,

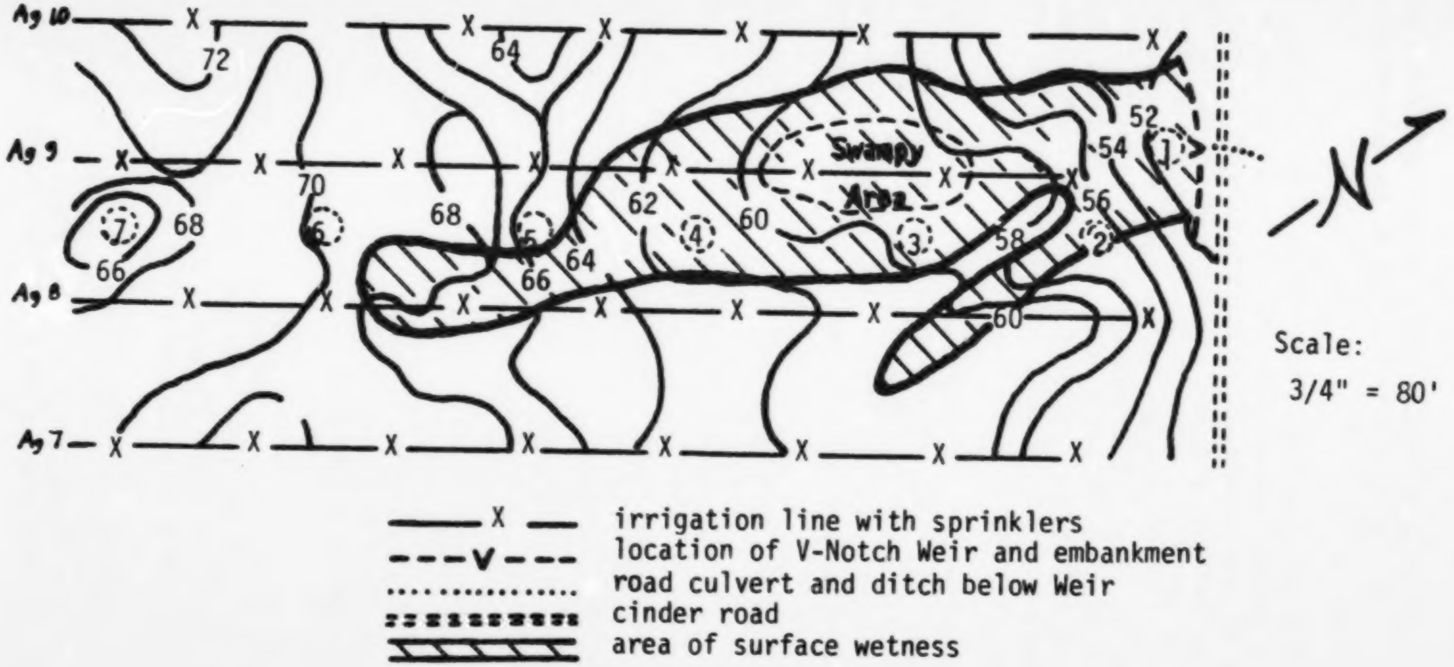

Ag 10
Ag 9
Ag 8
Ag 7
72
64
70
68
68
66
66
64
62
60
58
60
56
54
52
1
2
3
4
5
6
7
Swampy Area
N
Scale:
3/4" = 80'
irrigation line with sprinklers
location of V-Notch Weir and embankment
road culvert and ditch below Weir
cinder road
area of surface wetness

Figure 36. Topographic Map with Seepage Areas Delineated by Shading Two Days After Irrigation.

that applications of two inches of sewage effluent, at rates of 0.25 inches per hour, caused considerable quantities of total runoff. This runoff consisted of surface runoff and subsurface flow which reappeared down slope as seepage, and consequently contributed to the total runoff. This runoff as subsurface flow persisted for several days after irrigation under wet conditions. The perched water table, which is usually at the ground surface, if runoff does occur, slowly declined until the soil water conditions were such that hydraulic gradients no longer were strong enough to cause this lateral subsurface flow and resulting seepage. The above description of the drainage conditions, as well as the underlying causes and conditions discussed, represent the results of this hydrologic investigation.

The 1966-1967 Runoff Investigation

Site Description and Procedures. This study in the Gamelands Area included approximately 2.5 acres of a Morrison sandy loam soil with a vegetative covering of red clover. Piezometers were installed on 2-foot centers at depths of 2, 4, 6, 8, and 10 feet at each of five stations on approximately 40-foot intervals from top to bottom of the watershed. Diversions about 8 inches deep were installed at the base of the slope to intercept both surface and shallow subsurface flow and conduct it to a V-notch weir equipped with a stilling well and liquid level recorder. Rainfall records were obtained from a nearby U.S. Weather Bureau type, 8-inch rain gage. Three test cycles were included in this study and occurred respectively in October-November, 1966 (Cycle I); March-April, 1967 (Cycle II), and June-July, 1967 (Cycle III). Each cycle was composed of six runs occurring at weekly intervals. The amount applied per run was increased by 1 inch each week from 1" the first week to 6" the last week, however, the application rate always was kept at 0.25 inches per hour. The run number corresponds to the depth of irrigation water applied that week.

Runoff from the watershed consisted of surface flow, subsurface flow within the 8-inch surface layer and interflow. Interflow is defined as water which first infiltrated and then, after moving laterally, reappeared on the surface.

Hydrologic Measurements. The amount of precipitation that occurred during the week prior to irrigation for each of the runs and the runoff for all cycles, presented as percentage of irrigation amount appearing as runoff (R/I), are shown in Table 23.

The largest average percentage of irrigation appearing as runoff occurred in Cycle II; the smallest occurred in Cycle III. This occurred even though more total precipitation fell in the weeks prior to each run in Cycle III (7.71 inches) than in Cycle II (5.77 inches). The probable reason for the lower percentage of runoff during Cycle III was that this cycle occurred in June and July during which time the crop and climatic conditions caused a much greater evapotranspiration loss than in March and April of Cycle II. The maximum percent runoff (26.2%) occurred in Run 2 of Cycle II, and was associated with a seven-day antecedent precipitation of 3.44 inches.

Table 23. Percentage of Irrigation Amount Appearing as Runoff (R/I) and Inches of Total Precipitation which Occurred During the Week Prior to Irrigation for all Cycles

Runs	Cycle I (Oct-Nov) Runoff	Cycle I (Oct-Nov) Antecedent Precip	Cycle II (Mar-Apr) Runoff	Cycle II (Mar-Apr) Antecedent Precip	Cycle III (June-July) Runoff	Cycle III (June-July) Antecedent Precip
	percent	inches	percent	inches	percent	inches
1	0.0	0.16	9.0	0.23	0.0	0.41
2	4.1	0.40	26.2	3.44	0.0	0.08
3	11.7	0.00	18.0	0.91	3.5	2.36
4	20.4	0.38	13.4	0.51	8.9	1.58
5	25.0	1.27	14.0	0.35	17.4	1.41
6	19.0	0.00	16.4	0.27	21.6	1.87

Figure 37 depicts the irrigation, precipitation, and runoff versus time data for Cycle II, and similar data for Cycle III are presented in Figure 38. During the June-July cycle (Cycle III) there was no runoff for application amounts of 1 and 2 inches, but the percentage of runoff increased as the amount of irrigation increased from 3 through 6 inches. This indicates that as the soil profile filled with water, percolation rate within the soil profile was controlling runoff from the watershed. Also, it should be noted in Figure 38 that runoff decreased sharply immediately after the termination of irrigation but persisted for another 12 to 24 hours in a hydrograph pattern which is typical for interflow.

The runoff hydrographs for the March-April cycle, shown in Figure 37, are not as uniform as those for the June-July cycle. The runoff peaks do not always occur simultaneously with the termination of irrigation and the peaks are not always followed by rapidly declining recession curves. These non-uniformities were due primarily to the temperature changing from above to below freezing and vice versa. These temperature changes controlled the amounts of water being stored as ice or released from ice on the watershed.

The height of water rise inside a piezometer indicates the water pressure at its base. Piezometers therefore monitor changes in hydraulic pressure of water in the soil pores. Typical pressure head

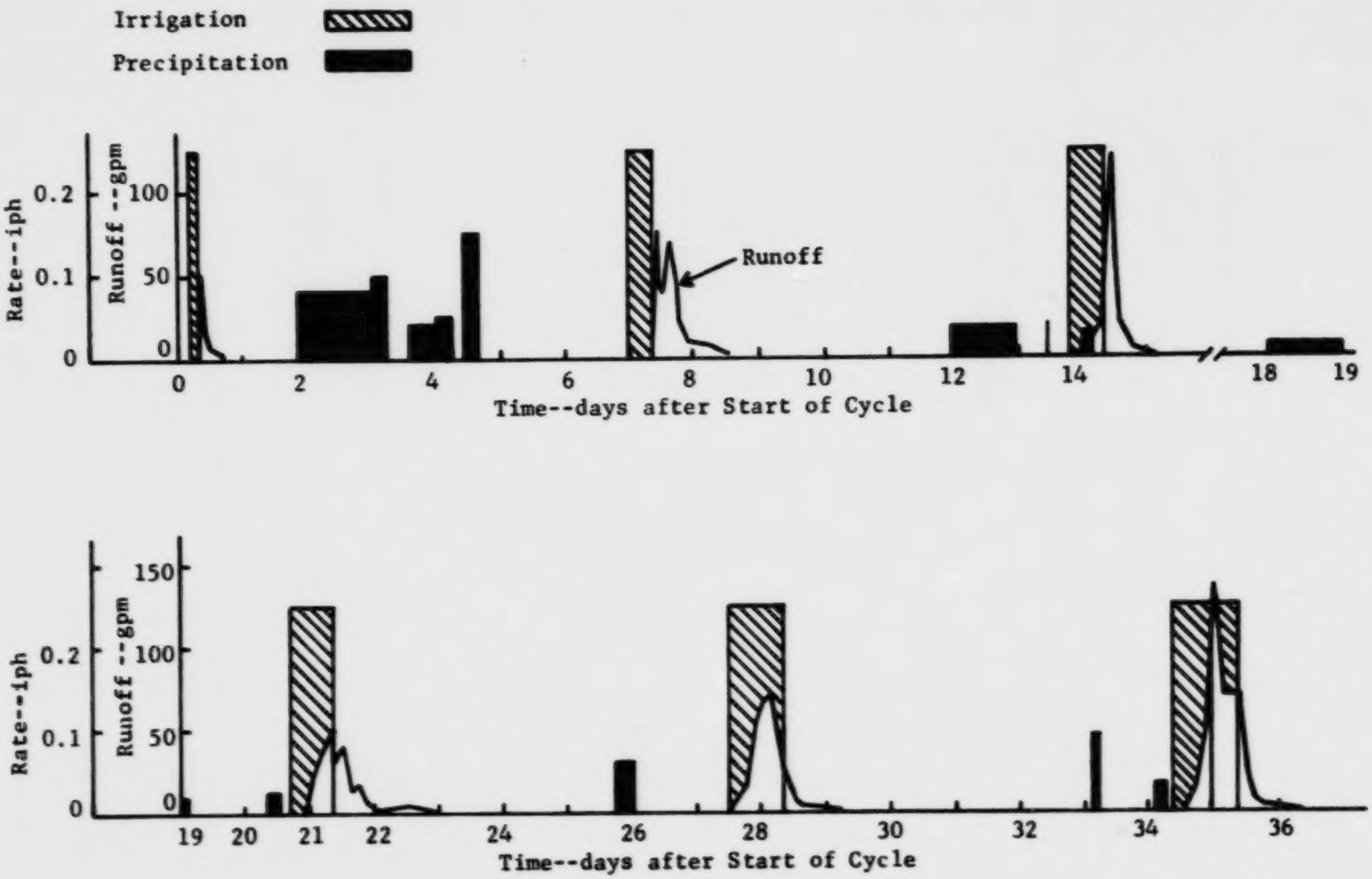


Figure 37. Irrigation, Precipitation and Interflow Runoff at Various Times After Start of Cycle II, Mar. - Apr., 1967.

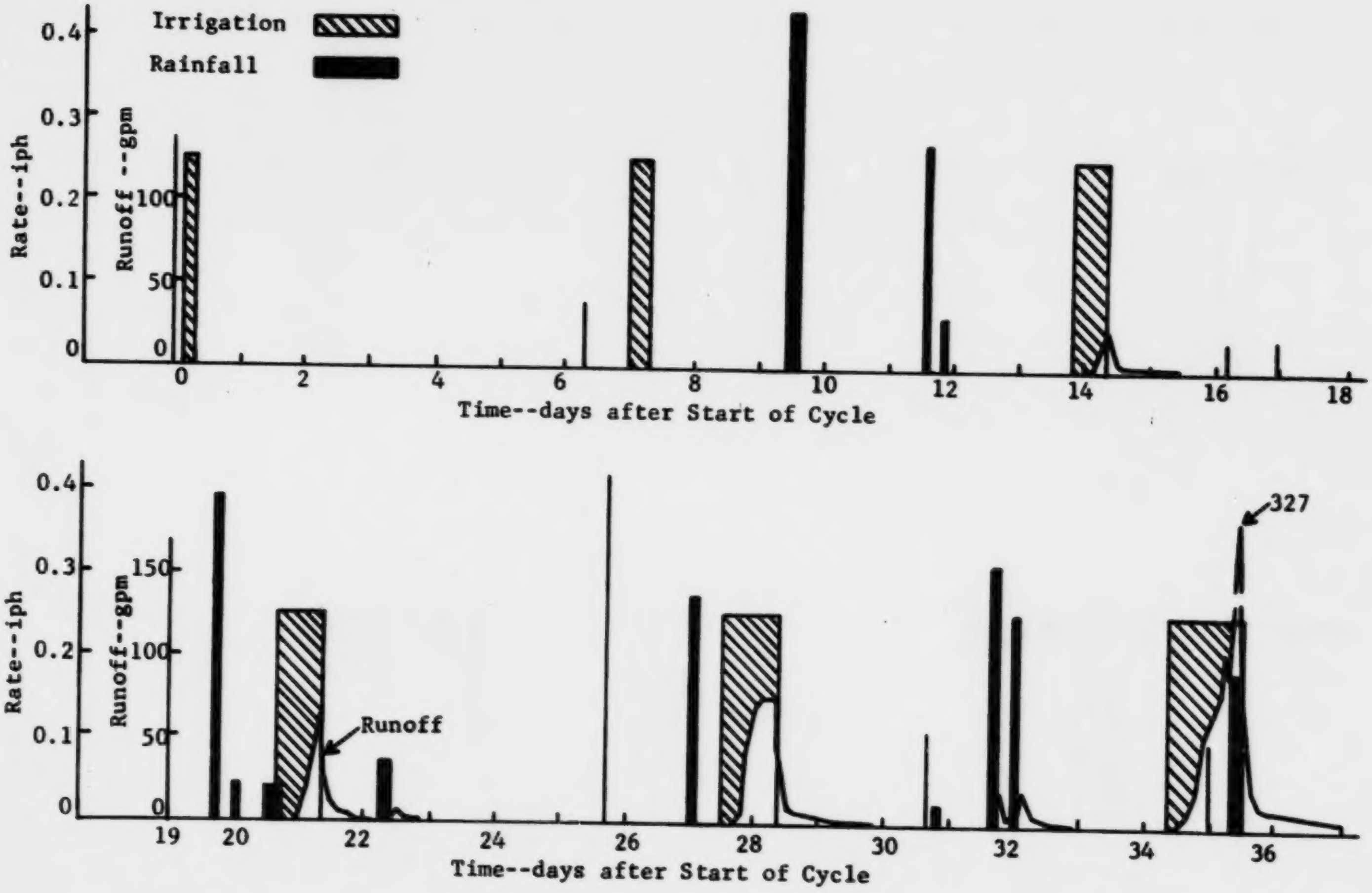


Figure 38. Irrigation, Precipitation and Interflow Runoff at Various Times After Start of Cycle III, June - July, 1967.

versus time response patterns for all piezometers are shown in Figure 39. Throughout all cycles the same 15 piezometers continued to respond while 10 piezometers did not respond, as indicated by the nearly horizontal lines in Figure 39.

Piezometer response to irrigation was affected by textural stratification of the soil profile. Piezometers which terminated in clay layers showed little pressure head response to irrigation. Those which terminated in sandy layers respond rapidly, and at some sites artesian effects were noted.

Table 24 is based on the highest recorded pressure heads for each cycle and run, considering only those piezometers which showed marked response to irrigation. The data indicate that the piezometer peak pressure heads averaged over all five piezometer depths were the highest during Cycle II and the lowest during Cycle III. Correspondingly the greatest average percent runoff occurred in Cycle II.

Table 24. Average Peak Pressure Heads in Piezometers for the Six Runs and the Three Cycles

Run	Cycle I (Oct-Nov) Pressure Head	Cycle II (Mar-Apr) Pressure Head	Cycle III (June-July) Pressure Head
	ft	ft	ft
1	1.07	2.44	0.55
2	2.64	3.51	0.94
3	2.97	3.73	2.81
4	3.24	3.69	3.20
5	3.52	3.77	3.41
6	3.42	3.74	3.66

The 1968-69 Runoff Investigation

Site Description and Procedures. This study on the same Hublersburg soil site used by Myers (14) was conducted to determine the difference between the watershed's responses with respect to runoff peak rates, total runoff volumes, and chemical quality of the runoff under two irrigation procedures. The one irrigation procedure applied effluent to the entire watershed simultaneously to maximize its hydrologic response, while the second procedure applied effluent during a sequence of times to minimize its hydrologic response.

Twenty-one sprinklers on four irrigation lines covering the watershed, lines Ag 7, 8, 9, and 10, were run simultaneously for the maximum

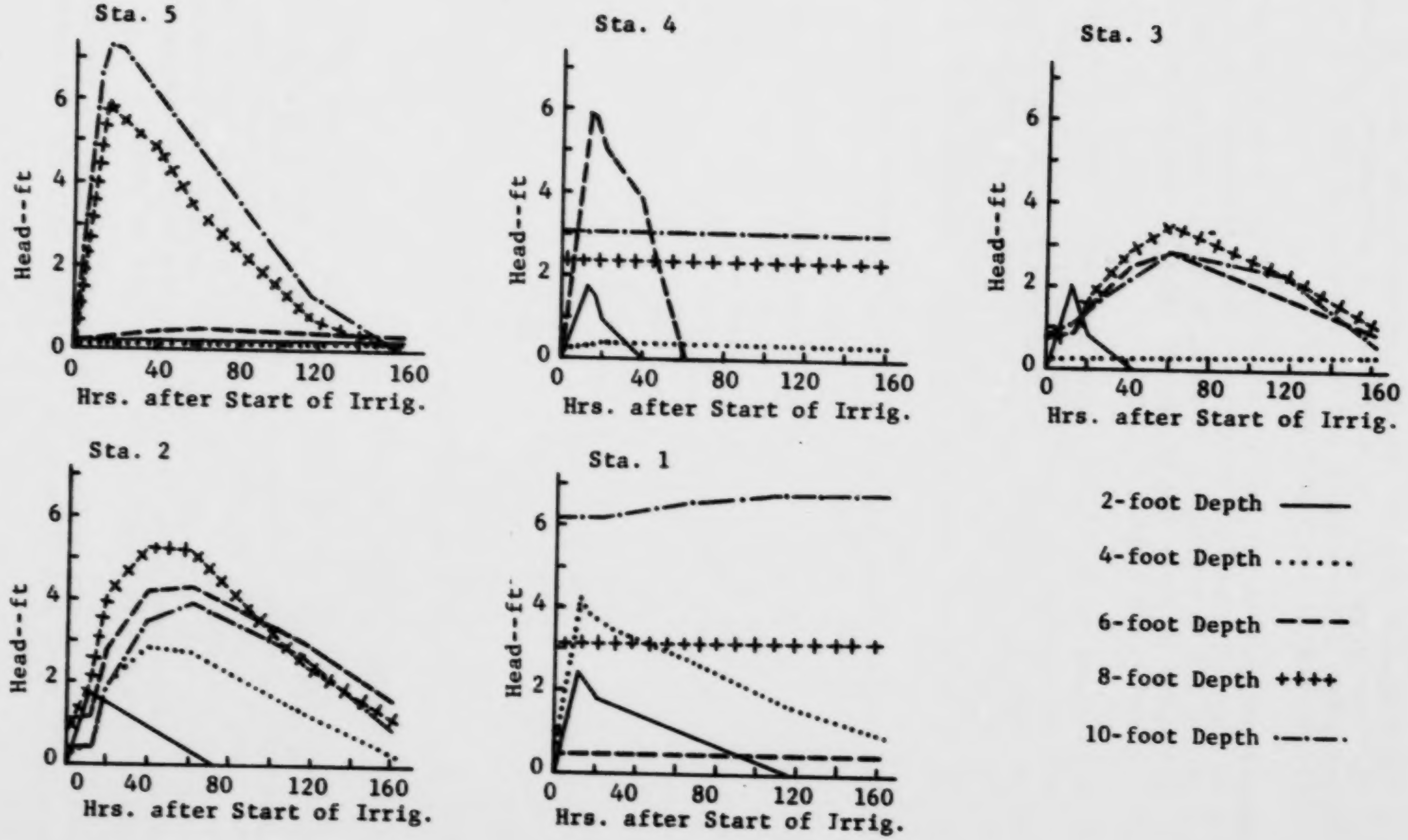


Figure 39. Piezometer Heads (P/W) vs. Hours After Start of 3-inch Irrigation for All Stations and Depths During Cycle I, Oct., 1966.

procedure, whereas during a typical minimum procedure line Ag 9 with seven sprinklers was run on Monday, Ag 7 and 10 with a total of 15 sprinklers were run on Wednesday, and Ag 8 with 8 sprinklers was run on Friday. Each run was for an eight-hour period and applied the equivalent of two inches of effluent. Each application procedure was referred to as a sequence and either a minimum or maximum sequence was run in any one week. A series of sequences run during a particular climatic period was a cycle. A cycle consisted of a minimum and maximum sequence each preceded by a preliminary sequence designed to establish appropriate hydrologic conditions. The sequence, areas irrigated, and dates of each of the five cycles composing this study are listed in Table 25.

In addition to securing piezometer, shallow well, and runoff data, soil temperature was measured at the locations at depths of 0, 3, 6, 12 and 18 inches with thermistor probes installed in place. Runoff data were recorded continuously but other data were taken at the time irrigation started, runoff started, irrigation stopped, and runoff stopped.

Hydrologic Measurements. Figure 40 presents typical irrigation precipitation, and runoff data plotted against time. These data are for Cycle III run during February-March of 1969. Table 26 lists the percentage of effluent volume applied which appeared as runoff during the minimum and maximum sequences for the five irrigation cycles. Cycle I and IV are typical of early fall and late spring irrigations, where greater percentages of water run from the area and higher peak rates of runoff occurred during the maximum sequence than during the minimum sequence. Cycles II and III, run during periods when soil frost essentially stopped infiltration and the surface was coated with ice, gave more runoff and higher peak rates of runoff during the minimum sequence because more of the applied effluent was stored on the landscape as ice during the maximum sequence. Cycle V is typical of irrigating during the growing season where no runoff occurred due to the irrigation.

Peak runoff rates relative to irrigation application rates for the five cycles are given in Table 27. Cycles I and IV are again what one would expect, where greater peaks occur from the maximum sequences than from the minimum sequences. The minimum sequences of Cycles II and III, however, produced greater peak flow than the maximum sequences. The maximum air temperature data during these cycles, listed in Table 28, help explain this atypical response. It so happened that during the maximum sequences it was sufficiently cold to form ice which was retained on the watershed, while during the minimum sequences the applied water was not immobilized as ice and it was warm enough to melt some of the previously stored ice.

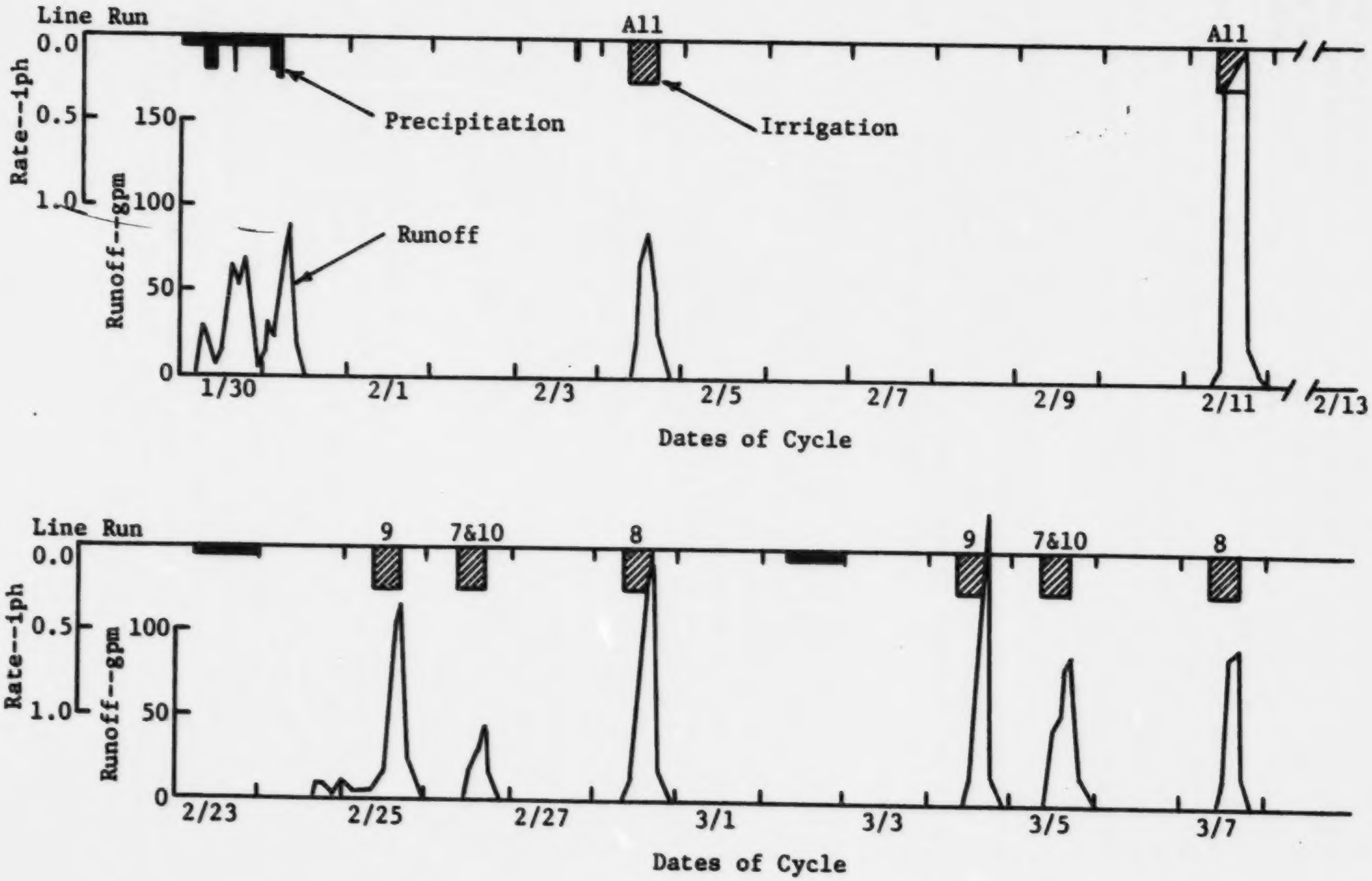


Figure 40. Irrigation, Precipitation and Runoff During Cycle III, Feb. - Mar., 1969.

Table 25. Sequences, Areas Irrigated and Dates of Each Irrigation Cycle

Cycle	Sequence	Area Irrigated Mon	Tues	Wed	Thur	Fri	Week beginning
	Pre-Min		9[a]	7&10		8	11/18/68
I	Minimum		9	7&10		8	11/25/68
	Pre-Max		All[b]				12/2/68
	Maximum		All				12/3/68
	Pre-Min		9	7&10		8	1/6/69
II	Minimum		9	7&10		8	1/13/69
	Pre-Max			All			1/20/69
	Maximum		All				1/27/69
	Pre-Max		All				2/3/69
III	Maximum		All				2/10/69
	Pre-Min		9	7&10		8	2/24/69
	Minimum		9	7&10		8	3/3/69
	Pre-Max		All				3/24/69
IV	Maximum		All				3/31/69
	Minimum		9	7&10		8	4/7/69
	Pre-Max	All					5/26/69
V	Maximum	All					6/2/69
	Pre-Min	9		7&10		8	6/23/69
	Minimum	9		7&10		8	6/30/69

[a] Numbers given under "Area Irrigated" indicate the irrigation lines in the Agronomic Area which ran that day.

[b] "All" indicates the maximum sequence with lines Ag 7, 8, 9 and 10 irrigating simultaneously.

Table 26. Percentage of Effluent Volume Applied Appearing as Runoff during the Minimum and Maximum Sequences for Five Irrigation Cycles

Cycle	Minimum Sequence	Maximum Sequence
I	23	27
II	55	34
III	84	56
IV	11	20
V	0	0

Table 27. Peak Runoff Rates Relative to Irrigation Application Rates during the Minimum and Maximum Sequences for the Five Irrigation Cycles

Irrigation Sequence	Area Irrigated	Irrigation Cycle				
		I	II	III	IV	V
		%	%	%	%	%
Maximum	Ag 7, 8, 9 & 10	43	52	76	36	0
Minimum	Ag 9	48	108	211	37	0
Minimum	Ag 7 & 10	24	88	85	6	0
Minimum	Ag 8	36	41	83	18	0
Minimum[a]	Ag 7, 8, 9 & 10	36	79	126	20	0

[a] Values given in this row are the peak runoff rates for the entire watershed obtained by averaging the peak runoff rates for the individual runs (Ag 9, Ag 7 & 10 and Ag 8) during the minimum sequences.

Table 28. Maximum Air Temperatures and Peak Rates of Runoff Relative to Irrigation Application Rates for Cycles II and III

Cycle	Sequence	Area Irrigated	Air Temperature During Irrigation Period		Relative Rate of Runoff
			°F		percent
			Max	Min	
I	Minimum	Ag 9	42	25	48
		Ag 7 & 10	44	40	24
		Ag 8	45	38	36
	Maximum	All	25	5	43
II	Minimum	Ag 9	34	27	108
		Ag 7 & 10	34	22	88
		Ag 8	33	32	41
	Maximum	All[a]	28	8	52
III	Maximum	All	33	19	76
	Minimum	Ag 9	40	26	211
		Ag 7 & 10	35	19	85
		Ag 8	32	28	83

[a] "All" indicates that lines Ag 7, 8, 9 and 10 irrigated simultaneously.

Runoff Water Quality Measurements. Phosphorus and nitrogen content of the applied effluent and of the runoff for the five cycles are given in Table 29. The concentrations of these two elements were smaller in the runoff samples than in the applied effluent for Cycles I and IV during which time the effluent could infiltrate and percolate through the upper soil layer. During Cycles II and III, a concrete soil frost diminished infiltration and the nutrient level of the runoff frequently was higher than in the applied effluent due to "freeze concentration" of the impurities as pure water was frozen out.

Results from this study, thus indicate that during periods when infiltration and percolation rates are not decreased by soil frost, sequencing the application of effluent irrigation is advantageous. During periods when soil frost essentially prevented infiltration and the surface was coated with ice, however, sequencing had no beneficial effect on total runoff but did result in a generally lower content of phosphorus and nitrogen in the runoff. If samples of runoff during irrigation with lines 7, 8 and 10 in the minimum sequence had been averaged with that from line 9 concentration of both phosphorus and nitrogen would have been even lower in the minimum sequence.

Table 29. Concentrations in Parts Per Million of Phosphorus and Nitrogen and Percent Change in Concentration in Watershed Runoff at Four Sampling Times for Four Irrigation Cycles

PHOSPHORUS

Minimum Sequence[a]

	Irrigation Cycle								
	I		II		III		IV		Average
Sampling Times	P	% Change	P	% Change	P	% Change	P	% Change	% Change
	ppm		ppm		ppm		ppm		
Applied Effluent	11.75		10.00		6.12		7.50		
Runoff Started	7.00	-40	13.75	+37.5	5.25	-14	1.62	-78	
Irrigation Stopped	6.88	-41	10.00	0	3.50	-43	1.38	-82	
Runoff Stopped	4.62	-60	10.82	+8	3.38	-45	0.70	-90	
Average		-47		+15		-34		-83	-37

Maximum Sequence

	Irrigation Cycle								
	I		II		III		IV		
Sampling Times	P	% Change	P	% Change	P	% Change	P	% Change	
	ppm		ppm		ppm		ppm		
Applied Effluent	10.12		5.80		7.50		7.25		
Runoff Started	12.50	+24	6.05	+4	9.68	+29	4.25	-41	
Irrigation Stopped	13.00	+28	5.45	-6	5.50	-27	4.15	-43	
Runoff Stopped	13.75	+36	7.65	+32	5.68	-32	1.62	-77	
Average		+29		+10		-10		-54	-6

Table 29. (continued).

TOTAL NITROGEN (includes organic N, NH_3-N and No_3-N)

Minimum Sequence[a]

Sampling Times	Irrigation Cycle I N	 % Change	 II N	 % Change	 III N	 % Change	 IV N	 % Change
	ppm		ppm		ppm		ppm	
Applied Effluent	30.10		42.70		33.50		31.00	
Runoff Started	19.40	-16	48.00	+12	33.54	0	8.50	-73
Irrigation Stopped	24.20	-20	42.30	- 1	26.02	-22	10.30	-67
Runoff Stopped	-	-	43.04	+ 1	29.04	-13	-	-
Average				+ 4		- 9		

Maximum Sequence

Sampling Times	Irrigation Cycle I N	 % Change	 II N	 % Change	 III N	 % Change	 IV N	 % Change	 Average % Change
	ppm		ppm		ppm		ppm		
Applied Effluent	20.50		32.66		35.40		27.20		
Runoff Started	26.70	+30	35.40	+ 8	53.56	+52	21.70	-20	
Irrigation Stopped	24.00	+17	37.24	+14	30.26	-15	22.90	-16	
Runoff Stopped	31.90	+56	44.84	+37	33.76	- 5	16.30	-40	
Average		+37		+20		+11		-25	+10

[a] Values listed for the minimum sequences are those concentrations secured from samples taken on the day line Ag 9 ran.

SECTION VI

CROPLAND ASPECTS

Effect of Effluent on Agronomic Crops

Previous Studies. The effect of sewage effluent on the yield of agronomic crops has generally been found to be a beneficial one. Henry et al. (24) obtained a significant increase in the yield of reed canarygrass. The authors concluded that nutrients such as nitrogen, phosphorus and potassium were being removed by the crop since there was little in the percolate. A similar conclusion was made by Heukelekian (25).

Irrigating by canals and ditches, Stokes et al. (26) obtained yield increases amounting to 240 percent for both Napier grass and Japanese cane when compared with the unirrigated crops. He states that yields from plots irrigated with well water were not significantly higher than the unirrigated plots and concluded that the difference was due to nutrients supplied in the effluent. In the effluent the nitrate concentration was zero ppm but free ammonia was 27.3 ppm and P_2O_5 8.2 ppm Day and Tucker (27, 28) applied three acre-feet of sewage effluent containing a total of 195 pounds of nitrogen, 150 pounds of phosphoric acid and 96 pounds of potash to plots on which barley, wheat and oats were grown for hay. Compared with crops irrigated with well water only, the effluent-irrigated crops increased in yield by 112 percent for barley, 263 percent for wheat and 249 percent for oats. When commercial fertilizers were added to the well water and the effect compared with that of sewage effluent, barley yielded 22 percent less when irrigated with the effluent but wheat and oats yielded more. This was believed to indicate a sensitivity of barely to sewage effluent. The lower yield of barley was attributed to its greater sensitivity to the presence of detergents in the effluent and to the higher accumulation of soluble salts in the effluent-irrigated plots. The yields of grain produced in the same experiment were reported by Day et al. (29). Compared with plots irrigated with well water without fertilizer, those irrigated with sewage effluent gave increases of 190 percent for barley, 163 percent for oats and 200 percent for wheat. Grain yields with well water and fertilizer equivalent to the N, P_2O_5 and K_2O in the sewage effluent were 300-400 lbs per acre less than with the sewage effluent. The only unfavorable feature of the effluent irrigated plots was the lodging that occurred. It was evident however that small grain crops could utilize nitrogen from sewage effluent as efficiently as from commercial fertilizers.

Using papermill waste, Vercher et al. (30) obtained a significant increase in the yield of corn compared with the unirrigated crop. However, there was no significant difference between the yields from

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plots irrigated with well water or waste water. Neither oats nor cowpeas showed a significant difference in yield between treatments.

Site Description and Procedures. The agronomic crops were grown on a site which had been producing hay, small grain, and corn for many years and had been receiving normal amounts of lime, manure and fertilizer. The area selected for the wastewater research, designated in Table 3 as Agronomy Area (A), was located on a Hublersburg soil with a surface texture ranging from silt loam to clay loam to silty clay loam to clay. The area ranged in slope from 3% to 16% and averaged about 4%. The strip-crop area was divided into three adjacent plots, each 800 feet long and 240 feet wide (4.4 acres each) as shown in Figure 41. The crops were grown in seven strips across the slope in a rotation sequence as indicated in Table 30.

The control plot (A-0) received commercial fertilizer in amounts normally recommended for the individual crops but received no irrigation. The irrigated plots (A-1 and A-2) received no commercial fertilizer. The reed canarygrass area (A-3), occupying 16 acres adjacent to the rotation area, was seeded in 1964, has been irrigated with wastewater year-round since then, and has received no commercial fertilizer. The irrigation systems and programs for these three areas are given in Table 3 and Table 31.

Crop response was measured in terms of yields and chemical quality. Forage harvests were made two or three times per year by mowing and weighing six strips, each 30 feet by 3 feet, in each rotation strip and in the reed canarygrass area. Subsamples were taken for determination of dry matter and subsequently ground in a Wiley mill in preparation for chemical analysis.

Corn grain yield was determined by removing and weighing ears along six randomly selected 30-foot rows in each rotation strip. Subsamples of kernels were removed from each ear and composited for determination of moisture by a dielectric method and grain yield converted to 15.5% moisture basis. After oven drying the grain was ground for chemical analysis.

Corn stover or silage was cut by hand from six randomly selected 30-foot rows in each rotation strip and weighed in the field. Three representative stalks were selected from each lot, weighed, then oven dried to determine dry matter content. These subsamples were ground in a hammer mill and then a sub-subsample ground in a Wiley mill in preparation for chemical analysis.

Yield of the only wheat harvest was measured by combining six strips, each 87 feet long x 10 feet wide in each rotation strip and weighing the bagged grain. Oats were hand cut with a sickle from randomly

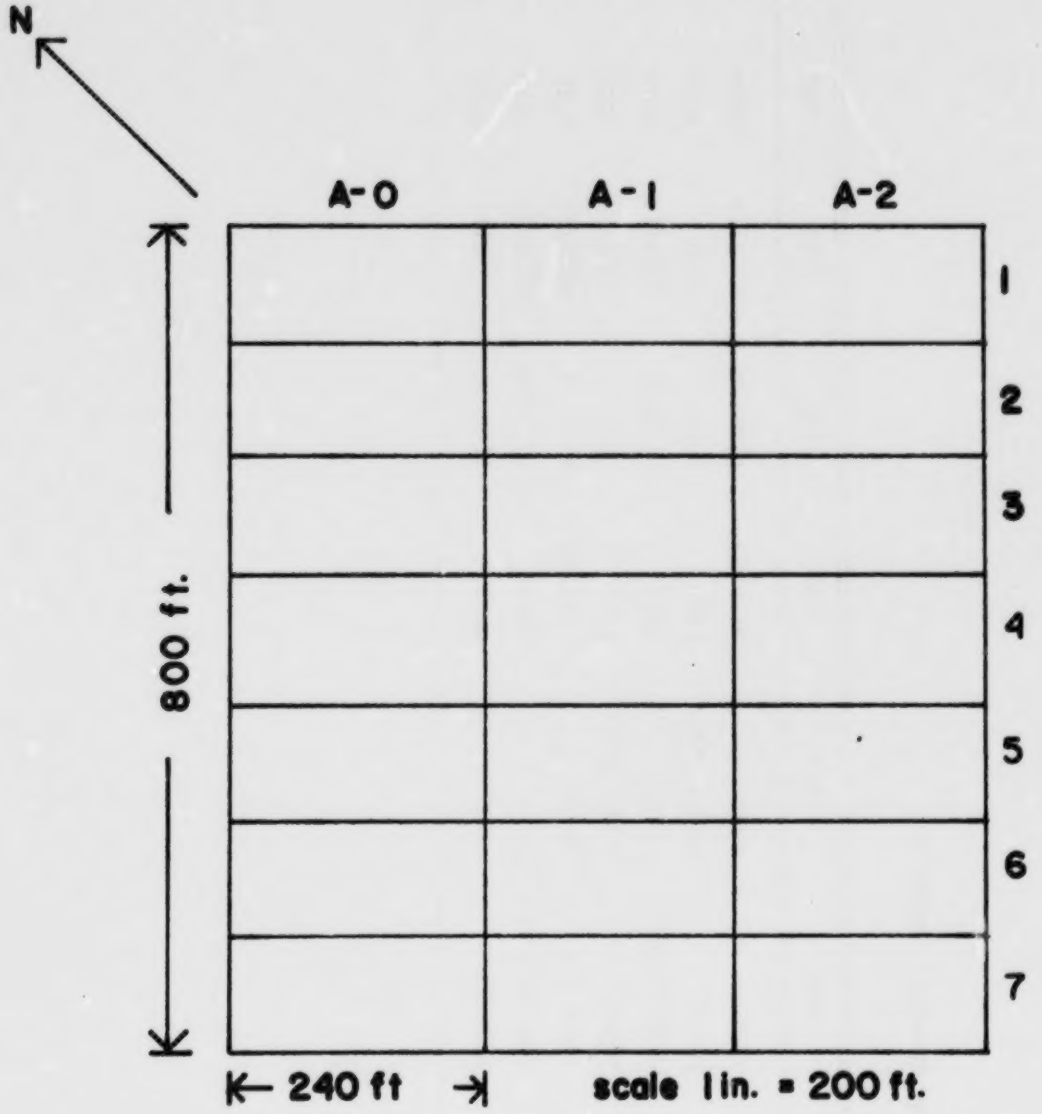
N
A-0
A-1
A-2
1
2
3
4
5
6
7
800 ft.
240 ft
scale 1 in. = 200 ft.

Figure 41. Plan of Strip Cropped Area.

Table 30. Crop Rotation Sequence

Strip Number	1963	1964	1965	1966	1967	1968	1969
1	corn	oats	alfalfa	alfalfa	alfalfa	corn	corn
2	wheat	red clover	corn	corn	corn	corn	corn
3	red clover	corn	oats	alfalfa	alfalfa	corn	corn
4	wheat	red clover	corn	corn	corn	corn	corn
5	corn	oats	alfalfa	alfalfa	alfalfa	corn	corn
6	red clover	corn	oats	alfalfa	alfalfa	corn	corn
7	alfalfa	corn	oats	alfalfa	alfalfa	corn	corn

Table 31. Irrigation Program for Agronomy Areas

Area No.	Weekly Application Inches	Seasonal Irrigation Amounts - inches							Total
		1963 June-Dec	1964 Mar-Nov	1965 Apr-Nov	1966 Apr-Nov	1967 Apr-Nov	1968 May-Sept	1969 May-Sept	
A-1	1	24	33	29	32	26	20	16	180
A-2	2	48	66	58	64	52	40	32	360
			July-Nov	Apr-Dec	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec	
A-3	2	-	36	80	78	94	98	100	486

selected sub-plots, 30-feet by 3.5 feet, in each rotation strip. The oats were threshed in a small head thresher and grain and straw yields determined from the separate weights. Subsamples of grain and straw were ground in preparation for chemical analysis. The methods used in chemically analyzing the plant materials are given in the appendix.

Crop Yields. The crop yields and percentage differences in yield due to sewage effluent application are given in Tables 32 through 38. With the exception of the wheat crop in 1963 which essentially had made its growth before irrigation began on June 19, and the oat crops in 1964 and 1965, increases in yield due to irrigation with the wastewater were highly significant (P=.01) for all rotation crops in 1963, 1964, 1965, and 1966. The oat yield differences were large but lodging caused a high degree of variation from sub-plot to sub-plot and hence diminished its statistical reliability. Rainfall in the growing season of years 1963-1966 was substantially below normal, as shown in Table 39, hence the favorable response was in part due to the added water on the irrigated plots. In most cases the 2-inch per week treatment was not significantly different from the 1-inch. Exceptions where the 2-inch treatment out yielded the 1-inch occurred with alfalfa in 1965, 1966 and 1967 and with both corn grain and silage in 1966.

During the more moist growing seasons of 1967, 1968 and 1969 yield response to irrigation with wastewater was less dramatic but did occur with grain corn (Pa. 444 in 19-inch rows) and alfalfa in 1967. In 1968 only corn was grown on the rotation strips. An attempt to control weeds with 2-4D rather than atrazine failed and the corn crop was smothered in weeds. Hence no yield measurements were made. In 1969 yield differences due to irrigation treatment were not significant. The control plot had plenty of fertilizer and water to make a good yield.

The 2-inch irrigated reed canarygrass yields were slightly greater than the 2-inch irrigated alfalfa and red clover hay yields. Although a reed canarygrass control area was not available for comparison the growth of reed canarygrass on unirrigated, unfertilized edges of the area was substantially less. In 1972, yield from an unirrigated, unfertilized plot was only 40% of that from the 2-inch irrigated area.

Crop Composition and Quantities of Nutrients Removed. Nutrients taken up by the growing crops from the applied wastewater should result in its renovation. To the extent that the nutrients are removed as harvested crops and recycled through man's food chain, the crops are a very important component of the "living filter" system of wastewater renovation.

A close examination of the nutrient content of the rotation crops in Tables 40 through 48 and Appendix Tables 1-6 indicates that, out of 64 crop-treatment cases cited, effluent irrigated crops contained more

Table 32. Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1963

Crop	0 Inch Per Week	1 Inch Per Week		2 Inches Per Week	
	Yield	Yield	% Increase	Yield	% Increase
Corn Grain (bu/a)*	75.0a**	105.4b	41	106.1b	41
Corn Stover (t/a)***	4.3a	6.7b	55	6.8b	58
Wheat Grain (bu/a)	48.0a	44.9a	-6	53.5a	13
Red Clover 1st cut (t/a)****	1.61a	2.70b	68	2.14b	33
Red Clover 2nd cut (t/a)****	0.87a	2.20b	153	2.45b	182
Red Clover total (t/a)****	2.48a	4.90b	98	4.59b	85
Alfalfa 1st cut (t/a)****	1.48a	1.89a	28	2.76b	86
Alfalfa 2nd cut (t/a)****	0.70a	1.84b	163	2.36c	237
Alfalfa total (t/a)****	2.18a	3.73b	71	5.12c	135

*Bushels per acre, corrected to 15.5 percent moisture basis.

**Values in the same row not having a common letter were highly significantly different (P-0.01). The same designation also applies to Tables 33, 34, 35, 36, 37 and 38.

***Tons per acre, field moisture basis.

****Tons per acre, dry matter basis.

Table 33. Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1964

Crop	0 Inch Per Week	1 Inch Per Week		2 Inches Per Week	
	Yield	Yield	% Increase	Yield	% Increase
Corn Grain (bu/a)*	80.7a	120.9b	50	116.1b	44
Corn Stover (t/a)**	3.83a	7.29b	90	8.48b	121
Oats Grain (bu/a)	82.4a	124.5a	51	97.0a	18
Red Clover 1st cut (t/a)***	1.48a	3.38b	128	3.22b	118
Red Clover 2nd cut (t/a)***	0.28a	1.92b	586	1.90b	578
Red Clover total (t/a)***	1.76a	5.30b	201	5.12b	191

*Bushels per acre, corrected to 15.5 percent moisture basis.

**Tons per acre, field moisture basis.

***Tons per acre, dry matter basis.

Table 34. Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1965

Crop	0 Inch Per Week	1 Inch Per Week		2 Inches Per Week	
	Yield	Yield	% Increase	Yield	% Increase
Corn Grain (bu/a)*	63.3a	114.4b	81	110.8b	75
Corn Silage (t/a)**	3.11a	3.93b	26	4.32b	39
Oats Grain (bu/a)	44.9a	80.5a	79	72.5a	61
Oats Straw (t/a)**	1.62a	2.90a	79	2.63a	62
Alfalfa 1st cut (t/a)**	1.63a	2.72b	67	2.93b	80
Alfalfa 2nd cut (t/a)**	0.05a	0.89b	1680	1.38c	2660
Alfalfa 3rd cut (t/a)**	0.59a	1.06b	80	1.11b	88
Alfalfa total (t/a)**	2.27a	4.67b	106	5.42b	139

*Bushels per acre, corrected to 15.5 percent moisture basis.

**Tons per acre, dry matter basis.

Table 35. Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1966

Crop	0 Inch Per Week	1 Inch Per Week		2 Inches Per Week	
	Yield	Yield	% Increase	Yield	% Increase
Corn Grain (bu/a)*	33.4a	98.4b	295	115.5c	346
Corn Silage (t/a)**	2.47a	4.45b	80	5.68c	130
Alfalfa 1st cut (t/a)**	1.48a	2.17b	57	2.11b	42
Alfalfa 2nd cut (t/a)**	0.33a	1.13b	242	1.54c	367
Alfalfa 3rd cut (t/a)**	0.14a	0.56b	300	0.73c	421
Alfalfa total (t/a)**	1.95a	3.86b	98	4.38c	125

*Bushels per acre, corrected to 15.5 percent moisture basis.

**Tons per acre, dry matter basis.

Table 36. Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1967

Crop	0 Inch Per Week	1 Inch Per Week		2 Inches Per Week	
	Yield	Yield	% Increase	Yield	% Increase
Corn Grain Pa. 444					
19 inch row (bu/a)*	97.9a	101.1ab	3	121.7b	24
38 inch row (bu/a)*	91.6a	83.0a	-9	84.5a	-8
Corn Pa. 602-A					
Grain 19 inch row (bu/a)*	122.2a	120.9a	-1	113.5a	-7
Silage 19 inch row (t/a)**	4.43a	4.47a	<1	4.67a	5
Alfalfa 1st cut (t/a)**	1.35a	2.87b	113	2.99b	115
Alfalfa 2nd cut (t/a)**	1.08b	0.90a	-17	1.37c	40
Alfalfa total (t/a)**	2.43a	3.77b	55	4.36c	76

*Bushels per acre, corrected to 15.5 percent moisture basis.

**Tons per acre, dry matter basis.

Table 37. Crop Yields and Percentage Increase in Yields at Various Levels of Sewage Effluent Application - 1969

Crop	0 Inch Per Week	1 Inch Per Week		2 Inches Per Week	
	Yield	Yield	% Increase	Yield	% Increase
Corn Silage					
Pa. 890-S (t/a)*	6.90a	6.66a	-3	7.27a	5
Pa. 602-A (t/a)*	5.19a	5.77a	11	5.49a	6

*Tons per acre, dry matter basis.

Table 38. Yields* of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1965-1969

Year	1st Cut	2nd Cut	3rd Cut	Total Yields
1965	2.77	2.39	0.97	6.13
1966	2.57	1.37	0.38	4.32
1967	3.77	1.88	1.38	7.03
1968	3.00	2.09	-	5.09
1969	2.83	1.71	0.64	5.18

*Tons per acre, dry matter basis.

Table 39. Normal Monthly Precipitation and Deviations from the Normal - Inches

	May	June	July	Aug	Sept	Seasonal Deviation
Normal	4.00	3.35	3.53	3.43	2.60	
1963	-1.07	-1.09	+0.28	-0.93	-0.20	-3.23
1964	-3.49	-0.31	-0.84	+0.06	-1.47	-6.05
1965	-1.57	-2.10	-2.29	+0.32	+0.33	-5.31
1966	-0.86	-3.12	+0.58	-2.51	+2.45	-3.46
1967	+0.57	-1.87	+4.05	+0.80	+1.29	+4.84
1968	+1.98	+0.10	-1.92	-0.06	+1.05	+1.15
1969	-1.79	+0.05	+2.65	+0.68	-0.80	+0.79

Table 40. Average Nutrient Composition of Red Clover Hay Receiving Various Levels of Sewage Effluent Per Week. 1963-1964

	Crop Year and Inches of Effluent Applied Per Week					
	1963			1964		
Nutrient	0	1	2	0	1	2
				Percent		
Nitrogen	1.86	2.21	2.29	2.03	2.72	2.38
Phosphorus	0.217	0.266	0.266	0.191	0.326	0.294
Potassium	2.08	2.69	2.65	1.90	3.06	2.79
Calcium	1.060	1.296	1.298	0.672	0.948	0.653
Magnesium	0.162	0.227	0.236	0.140	0.315	0.233
Chloride	-	-	-	0.40	1.06	1.25
				Micrograms per grams		
Boron	-	-	-	15	26	15

Table 41. Average Nutrient Composition of Alfalfa Hay Receiving Various Levels of Sewage Effluent Per Week. 1963, 1965-1967

Nutrient	Crop Year and Inches of Effluent Applied Per Week											
	1963			1965			1966			1967		
	0	1	2	0	1	2	0	1	2	0	1	2
							Percent					
Nitrogen	1.75	1.92	1.87	2.12	2.66	2.62	2.91	2.35	2.14	1.82	1.54	2.10
Phosphorus	0.245	0.308	0.313	0.185	0.293	0.312	0.244	0.327	0.330	0.26	0.28	0.30
Potassium	1.95	2.25	2.28	2.04	2.55	2.75	2.48	2.83	2.78	2.21	2.39	2.53
Calcium	0.646	0.670	0.442	0.980	0.647	0.660	1.03	0.66	0.54	0.95	0.43	0.39
Magnesium	0.122	0.152	0.141	0.132	0.216	0.225	0.15	0.20	0.19	0.15	0.14	0.16
Chloride	-	-	-	0.53	1.16	1.23	0.55	1.07	1.22	0.62	1.04	1.18
							Micrograms per gram					
Sodium	-	-	-	14	16	19	23	224	197	31	154	157
Boron	-	-	-	-	-	-	17	14	10	17	9	8

Table 42. Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1963

	Crop and Inches of Effluent Applied Per Week								
	Corn Grain			Wheat Grain			Wheat Straw		
Nutrient	0	1	2	0	1	2	0	1	2
					Percent				
Nitrogen	1.79	1.69	1.70	1.99	2.37	2.58	0.73	0.84	0.92
Phosphorus	0.426	0.382	0.446	0.504	0.599	0.636	0.008	0.118	0.135
Potassium	0.37	0.32	0.47	0.47	0.43	0.37	0.99	0.96	1.09
Calcium	0.008	0.005	0.005	0.050	0.050	0.055	0.260	0.303	0.277
Magnesium	0.143	0.108	0.129	0.130	0.149	0.165	0.072	0.096	0.082

Table 43. Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1964

	Crops and Inches of Effluent Applied Per Week								
	Corn Grain			Corn Stover			Oat Grain		
Nutrient	0	1	2	0	1	2	0	1	2
					Percent				
Nitrogen	1.90	1.36	1.74	0.63	0.55	0.70	1.64	1.07	1.86
Phosphorus	0.187	0.163	0.166	0.076	0.061	0.158	0.372	0.465	0.477
Potassium	0.34	0.35	0.35	1.25	1.36	1.40	0.73	0.67	0.64
Calcium	0.050	0.050	0.050	0.480	0.370	0.330	0.140	0.120	0.130
Magnesium	0.077	0.068	0.066	0.168	0.185	0.160	0.145	0.145	0.153
Chloride	0.06	0.04	0.04	0.38	0.72	0.60	0.16	0.11	0.07
					Micrograms per gram				
Boron	4	4	4	10	11	10	5	8	6

Table 44. Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1965

	Crop and Inches of Effluent Applied Per Week											
	Corn Grain			Corn Silage			Oat Grain			Oat Straw		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
							Percent					
Nitrogen	1.78	1.75	1.81	1.45	1.36	1.29	2.03	1.99	1.55	0.43	0.29	1.12
Phosphorus	0.545	0.611	0.653	0.176	0.217	0.223	0.353	0.448	0.423	0.047	0.114	0.135
Potassium	0.57	0.60	0.63	1.12	1.01	1.18	0.83	0.57	0.56	2.48	1.94	1.86
Calcium	0.012	0.021	0.059	0.550	0.420	0.370	0.157	0.105	0.103	0.740	0.420	0.430
Magnesium	0.208	0.203	0.229	0.171	0.221	0.190	0.137	0.142	0.139	0.136	0.150	0.106
Chloride	0.03	0.04	0.06	0.25	0.37	0.38	0.22	0.09	0.09	1.35	1.03	1.50
							Micrograms per gram					
Boron	2	4	4	9	5	7	5	4	4	6	5	4

Table 45. Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1966

	Crop and Inches of Effluent Applied Per Week					
	Corn Silage			Corn Grain		
Nutrient	0	1	2	0	1	2
			Percent			
Nitrogen	1.90	1.42	1.25	2.51	1.96	1.95
Phosphorus	0.246	0.311	0.340	0.453	0.507	0.614
Potassium	1.05	1.07	1.16	0.38	0.44	0.45
Calcium	0.42	0.31	0.28	*	*	*
Magnesium	0.18	0.20	0.20	0.17	0.17	0.17
Chloride	0.33	0.40	0.39	0.04	0.05	0.07
			Micrograms per gram			
Sodium	13	250	211	5	5	8
Boron	5	5	5	*	*	*

* Less than 0.10% Ca and less than 5 micrograms B per gram.

Table 46. Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1967

	Crop and Inches of Effluent Applied Per Week											
	Corn Grain Pa. 444						Corn Pa. 602-A*					
	19" Row Spacing			38" Row Spacing			Grain			Silage		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
						Percent						
Nitrogen	1.48	1.61	1.50	1.81	1.63	1.82	1.68	1.63	1.64	1.00	1.06	1.18
Phosphorus	0.35	0.45	0.47	0.45	0.51	0.51	0.38	0.45	0.52	0.18	0.25	0.32
Potassium	0.33	0.37	0.36	0.40	0.39	0.40	0.37	0.43	0.44	1.23	1.23	1.36
Calcium	**	**	**	**	**	**	**	**	**	0.28	0.24	0.21
Magnesium	0.12	0.14	0.14	0.14	0.16	0.16	0.13	0.13	0.14	0.14	0.18	0.19
Chloride	0.07	0.06	0.02	0.04	0.05	0.02	0.05	0.06	0.02	0.32	0.38	0.39
						Micrograms per gram						
Sodium	12	13	5	25	6	4	16	18	9	22	160	188
Boron	2	2	3	2	3	3	2	3	2	4	6	7

*Nineteen inch row spacing.

**Average composition was less than 0.10 percent calcium for grain samples.

Table 47. Average Nutrient Composition of Crops Receiving Various Levels of Sewage Effluent Per Week - 1969

	Crop and Inches of Effluent Applied Per Week					
	Corn Silage Pa. 890-S			Corn Silage Pa. 602-A		
Nutrient	0	1	2	0	1	2
			Percent			
Nitrogen	1.83	1.67	1.63	1.63	2.16	1.80
Phosphorus	0.19	0.26	0.30	0.23	0.26	0.32
Potassium	0.88	0.89	1.03	1.13	1.27	1.16
Calcium	0.24	0.21	0.19	0.34	0.25	0.15
Magnesium	0.13	0.17	0.17	0.14	0.20	0.16
Chloride	0.27	0.36	0.37	0.34	0.42	0.32
			Micrograms per gram			
Sodium	26	112	123	10	163	165
Boron	4	4	5	7	7	5

Table 48. Average Nutrient Composition of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week. 1965-1969

Nutrient	1965	1966	Years 1967	1968	1969
			Percent		
Nitrogen	3.00	3.15	2.34	3.50	3.42
Phosphorus	0.33	0.39	0.40	0.46	0.45
Potassium	2.63	2.90	2.44	2.50	2.07
Calcium	0.54	0.33	0.46	0.40	0.47
Magnesium	0.25	0.22	0.29	0.28	0.35
Chloride	1.56	1.41	1.44	1.67	1.67
			Micrograms per gram		
Sodium	408	137	334	304	259
Boron	8	6	7	5	11

phosphorus in 92% and more potassium in 78% of the cases. However, although not as strongly expressed, the effect of effluent irrigation on nitrogen content was reversed. The fertilized but unirrigated crops contained more nitrogen in 53% of the cases. Irrigated hay crops (alfalfa and red clover) were more often higher in nitrogen, 54% of the cases, whereas irrigated corn and small grains were less often higher in nitrogen, 42% of the cases. Irrigated crops were generally not higher in calcium, only 18% were higher, or in boron, only 44% were higher. The latter occurred even though substantial amounts of boron were added in the applied effluent. However, irrigated crops were generally higher in magnesium, 80% of the cases, in chloride, 76% of the cases and sodium, 81% of the cases. Sodium and chloride is taken up by the plants in much larger amounts and the chloride content of the alfalfa crops was more than doubled. Although the sodium content of the crops was much lower than the chloride content its change in content as a result of irrigation with the wastewater is greater than with any other constituent. In alfalfa the sodium content increased 5 to 10 fold; in silage corn it increased 5 to 15 fold. The significance of these large increases in chloride and sodium for the nutritive value of these crops for animals is not evident at this time. Chlorides up to 1500 mg/l in livestock water has been reported safe for cattle, sheep, swine and poultry and a threshold limit of 2000 mgNa/l for livestock has tentatively been suggested (2).

The concentration of nitrogen in the 2-inch irrigated reed canarygrass was generally higher than in the alfalfa and red clover hays and averaged 3.08%. Phosphorus content averaged 0.4%, which exceeded that of the legume hays and corn silage and was slightly less than that in corn grain and oats. The average potassium content, 2.51% was slightly less than that in the 2-inch irrigated legume hays (2.63%) and much greater than in the grains or silage. Data for individual cuttings are given in Appendix tables 7 through 11.

Quantities of Nutrients Removed. The quantities of N, P, and K removed in the harvested crops (Tables 49 to 57) ranged from a low of 29.6 lb of N/acre for oats on the control area in 1965 to a high of 356 lb N/A for reed canarygrass in 1968. Corn silage removed substantially more N and K than corn grain but there was relatively little difference in the removal of phosphorus by grain and silage. The mixed legume-grass hay crops were about equally effective as corn grain or silage in removing phosphorus and removed substantially more potassium; 200 to 300 pounds of K per acre as against 20 to 30 pounds of K in corn grain and 100 to 150 pounds of K in corn silage. Data for the individual hay cuttings are given in Appendix tables 12-17. The greatest quantities of all nutrients was removed by the reed canarygrass. In five years, 1965-1969, it removed from each acre 1665 pounds of N, 224 pounds of P and 1384 pounds of K. The amounts removed by individual reed canarygrass cuttings is given in Appendix tables 18-22.

Quantities of Nutrients Applied and Renovation Efficiency of Crops. The various crops grown all contribute importantly in removing the two key eutrophic nutrients, P and N, which are being applied in the wastewater. Their respective renovating efficiencies for these and other constituents in the wastewater was determined by computing the ratio of the quantity of the constituent removed in the harvested crop to the quantity of the constituent added in the applied wastewater. The latter was computed from the analyses of the applied wastewater shown in Tables 58 and 59 and the volume of wastewater applied. The quantities applied annually are shown in Tables 60 and 61 and the computed renovation efficiencies in Tables 62 through 68.

Variations in composition of the wastewater occurred from year to year and between the one and two inch applications in any one year. These are due in part to the variations from year to year in the day of the week or period in the day when the irrigation occurred. One source of variation was the detergent industry change in surfactant (MBAS) from ABS prior to 1965 to LAS after 1965 which resulted in more complete decomposition of the surfactant in the treatment plant. Prior to 1965, MBAS averaged 2.69 mg/1; after 1965 it averaged only 0.43 mg/1. Changes in treatment plant operation and seasonal loads handled by the plant contributed to some of the variations in the various nitrogen components. Nitrate concentrations tended to be higher during the summer months when treatment plant loads were about 40% less than during

Table 49. Quantities of Nutrients (Pounds Per Acre) Removed by Red Clover Receiving Various Levels of Sewage Effluent Per Week. 1963-1964

	Crop Year and Inches of Effluent Applied Per Week					
	1963			1964		
Nutrient	0	1	2	0	1	2
Nitrogen	91.4	216.8	210.7	71.5	288.5	243.2
Phosphorus	10.8	26.0	24.4	6.8	34.5	29.6
Potassium	103.4	264.1	243.5	66.8	324.8	286.4
Calcium	52.6	127.0	119.2	23.7	100.4	66.7
Magnesium	8.0	22.3	21.7	4.9	33.7	23.8
Chloride	-	-	-	14.1	112.7	128.4
Boron	-	-	-	0.05	0.28	0.15

the regular academic year because of a reduction in student population of about 15,000 during the summer period.

Of the various constituents assayed, sodium and chloride were present in largest quantities and were being added annually in combined totals of 500 to 1300 lb/acre in the rotation crop area and 1400 to 2000 lb/acre in the reed canarygrass area. The three principal fertilizer nutrients were being added in the 2-inch per week treatment areas at average annual levels of 47 to 128 lbP/acre, 110 to 248 lbN/acre and 100 to 278 lbK/acre on the rotation crop area; and 95 to 188 lbP/acre, 155 to 525 lbN/acre and 222 to 373 lbK/acre on the reed canarygrass area. Annual boron additions in the 2-inch treatment ranged from 4.2 to 6.0 lbB/acre in the rotation crop area and from 5.2 to 8.9 lbB/acre in the reed canarygrass area. The quantities of major plant nutrients at the low end of the range are about equal to the amounts normally recommended for the crops grown. The quantities at the upper end of the range are within the limits which have been used in intensive management for maximum productivity.

The quantities of boron added annually in both the one- and two-inch treatments exceed the amounts normally recommended for the crops grown. However, the normal recommendation of approximately one lbB/acre per year for alfalfa, which has a high boron need, is usually put on in a single dose or two doses per season mode and hence results in a higher short time concentration. If larger amounts were added in a single application toxic limits would be reached. The wastewater application

Table 50. Quantities of Nutrients (pounds per acre) Removed by Alfalfa Receiving Various Levels of Sewage Effluent Per Week. 1963, 1965-1967

	Crop Year and Inches of Effluent Applied Per Week											
	1963			1965			1966			1967		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
Nitrogen	76.1	143.2	191.7	96.5	248.1	283.9	112.4	179.6	184.8	70.0	114.9	132.9
Phosphorus	10.7	23.0	32.0	8.5	27.6	33.6	9.7	25.0	28.6	8.6	21.3	24.3
Potassium	85.0	167.9	234.0	92.3	237.9	298.0	95.8	219.5	242.1	74.6	181.1	209.0
Calcium	28.2	50.0	45.3	44.6	60.4	71.6	37.7	51.9	46.6	25.8	31.8	32.0
Magnesium	5.3	11.4	14.5	6.0	20.2	24.4	5.7	15.1	16.2	4.6	11.0	12.4
Chloride	-	-	-	24.1	108.1	133.3	21.4	83.0	105.5	20.4	77.5	94.8
Sodium	-	-	-	0.07	0.16	0.21	0.12	1.81	1.86	0.09	1.16	1.27
Boron	-	-	-	-	-	-	0.07	0.10	0.08	0.04	0.07	0.08

Tabel 51. Quantities of Nutrients (pounds per acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1963

	Crop and Inches of Effluent Applied Per Week								
	Corn Grain			Wheat Grain			Wheat Straw		
Nutrient	0	1	2	0	1	2	0	1	2
Nitrogen	81.4	108.0	109.0	57.2	63.8	82.7	14.7	9.6	16.0
Phosphorus	19.4	24.4	28.7	14.5	16.1	20.4	1.4	1.3	2.4
Potassium	16.8	20.6	29.9	13.4	11.7	11.9	20.1	10.9	19.0
Calcium	0.3	0.3	0.3	1.4	1.3	1.8	5.3	3.4	4.8
Magnesium	6.5	6.9	8.3	3.7	4.0	5.3	1.5	1.1	1.4

Table 52. Quantities of Nutrients (pounds per acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1964

	Crop and Inches of Effluent Applied Per Week								
	Corn Grain			Corn Stover			Oat Grain		
Nutrient	0	1	2	0	1	2	0	1	2
Nitrogen	105.5	103.8	141.3	50.6	81.2	118.5	41.8	42.3	56.1
Phosphorus	10.4	14.0	13.6	5.4	8.9	26.9	9.6	18.5	14.9
Potassium	18.8	29.5	28.6	94.4	197.4	237.6	19.1	26.6	19.9
Calcium	2.8	4.3	4.1	36.4	53.5	56.0	3.8	4.8	4.1
Magnesium	4.3	5.8	5.4	12.8	27.0	27.1	3.8	5.8	4.8
Chloride	3.2	3.8	3.4	11.7	32.8	30.3	4.0	4.5	2.1
Boron	0.02	0.04	0.03	0.04	0.05	0.05	0.01	0.03	0.02

Table 53. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1965

	Crop and Inches of Effluent Applied Per Week											
	Corn Grain			Corn Silage			Oat Grain			Oat Straw		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
Nitrogen	54.6	96.9	97.2	96.6	107.4	110.1	29.6	51.3	35.8	14.4	16.9	6.4
Phosphorus	16.7	33.9	35.2	11.8	16.9	18.9	5.1	11.4	10.0	1.5	6.6	7.3
Potassium	17.3	33.0	33.6	72.8	78.1	101.5	12.0	14.4	12.9	100.6	112.2	99.7
Calcium	0.4	1.2	3.2	35.5	32.3	31.6	2.3	2.7	2.4	28.8	24.1	22.5
Magnesium	6.4	11.3	12.3	11.2	17.4	16.4	2.0	3.6	3.2	5.4	6.1	5.6
Chloride	2.1	2.6	1.9	15.6	29.2	32.9	3.2	2.4	2.1	43.6	61.6	76.6
Boron	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.01	0.01	0.02	0.03	0.02

Table 54. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1966

	Crop and Inches of Effluent Applied Per Week					
	Corn Silage			Corn Grain		
Nutrient	0	1	2	0	1	2
Nitrogen	92.3	122.0	142.1	46.9	108.0	126.1
Phosphorus	12.1	27.2	38.3	8.5	27.9	39.7
Potassium	51.1	95.4	132.0	7.1	24.2	29.1
Calcium	20.4	27.4	31.1	*	*	*
Magnesium	8.8	18.4	22.3	3.2	9.4	11.0
Chloride	16.3	36.4	45.0	0.7	2.7	4.5
Sodium	0.06	2.24	2.49	0.01	0.03	0.05
Boron	0.02	0.05	0.06	*	*	*

*Quantities not computed because constituent was not determined.

Table 55. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1967

	Crop and Inches of Effluent Applied Per Week											
	Corn Grain Pa. 444						Corn Pa. 602-A*					
	19" Row Spacing			38" Row Spacing			Grain			Silage		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
Nitrogen	66.4	73.8	80.5	81.5	60.9	68.0	90.7	87.8	82.6	84.8	94.7	112.1
Phosphorus	16.0	20.4	25.1	20.3	18.5	19.9	20.8	24.0	26.2	16.3	22.5	30.1
Potassium	14.4	16.6	19.3	18.7	13.9	15.0	20.0	22.8	21.8	106.9	110.3	127.4
Calcium	**	**	**	**	**	**	**	**	**	25.9	20.9	20.2
Magnesium	5.2	6.5	7.2	6.4	5.7	6.0	6.9	7.1	7.1	17.1	15.5	17.6
Chloride	2.5	2.6	1.0	1.7	1.9	0.7	2.6	2.9	1.0	28.8	35.6	36.8
Sodium	0.06	0.06	0.02	0.11	0.02	0.01	0.08	0.09	0.05	0.19	1.40	1.75
Boron	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.06	0.07

*Nineteen inch row spacing.

**Less than 0.10% Ca in tissue, generally less than 6.8 pounds per acre.

Table 56. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1969

Nutrient	Crop and Inches of Effluent Applied Per Week					
	Corn Silage Pa. 890-S			Corn Silage Pa. 602-A		
	0	1	2	0	1	2
Nitrogen	265.4	224.9	235.6	173.1	258.8	198.1
Phosphorus	28.1	32.7	43.1	23.5	30.1	58.7
Potassium	128.0	120.0	146.5	116.4	145.4	97.0
Calcium	34.2	31.2	28.3	36.7	27.7	16.3
Magnesium	18.7	22.3	25.0	14.7	22.2	18.3
Chloride	38.4	48.0	51.4	34.5	47.8	33.7
Sodium	0.38	1.51	1.70	0.10	1.97	1.83
Boron	0.06	0.06	0.07	0.08	0.08	0.05

Table 57. Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week. 1965-1969

Nutrient	1965	1966	1967	1968	1969
Nitrogen	353.1	272.2	328.9	356.2	354.5
Phosphorus	40.0	33.4	55.9	47.2	47.2
Potassium	321.9	250.5	342.7	254.8	214.4
Calcium	62.0	28.8	64.6	40.7	48.7
Magnesium	29.8	18.9	40.6	27.9	36.2
Chloride	187.6	122.0	202.6	169.6	173.5
Sodium	4.76	1.18	4.69	3.09	2.68
Boron	0.10	0.05	0.10	0.05	0.11

Table 58. Average Concentration (mg/1) of Various Constituents in Wastewater Applied to the Rotation Crops at Rates of One and Two Inches Per Week - 1963-1969

	Concentration (mg/1)									
	1963		1964		1965		1966		1967	
Constituent	1	2	1	2	1	2	1	2	1	2
Phosphorus	9.680	9.720	8.620	8.545	6.310	6.935	5.970	5.370	4.930	6.725
MBAS	3.17	3.20	1.47	1.54	1.09	0.98	0.33	0.36	0.26	0.30
Nitrate-N	5.7	5.8	14.9	13.8	6.3	5.9	8.1	8.0	5.4	5.2
Organic-N*	7.3	7.3	3.7	2.8	2.9	2.5	6.5	4.6	4.0	4.0
Potassium	17.1	16.8	16.4	15.3	19.9	20.6	20.6	19.2	18.4	18.6
Calcium	32.4	32.3	35.6	35.0	24.8	25.3	30.1	28.9	22.6	22.6
Magnesium	18.5	19.0	19.2	19.1	13.4	14.0	19.8	18.4	11.3	12.2
Sodium	46.0	46.9	32.2	34.2	36.0	35.7	41.4	38.6	39.5	40.0
Manganese	**	**	**	**	**	**	0.08	0.08	0.16	0.12
Chloride	43.4	43.9	40.0	38.9	42.7	43.8	54.4	51.4	48.9	45.0
Boron	**	**	0.40	0.40	0.32	0.32	0.36	0.36	0.42	0.41
pH	7.3	7.3	7.2	7.3	7.5	7.6	7.6	7.7	7.6	7.8

*Values included ammoniacal nitrogen. For the period 1965-1967, values are underestimated due to loss of undetermined amounts of ammoniacal nitrogen during analysis. Method of analysis changed in 1968.

**Values not determined.

Table 58. (continued)

Constituent	Concentration (mg/1)			
	1968		1969	
	1	2	1	2
Phosphorus	5.345	7.105	4.675	6.560
MBAS	0.50	0.56	0.57	0.54
Nitrate-N	4.7	4.2	5.8	5.1
Organic-N	2.9	3.8	7.8	4.8
Ammoniacal-N	15.7	14.6	11.4	12.8
Potassium	16.7	17.1	15.2	13.8
Calcium	20.9	20.2	34.6	32.0
Magnesium	10.6	10.4	17.4	16.3
Sodium	37.4	40.8	51.5	52.8
Manganese	0.36	0.18	0.12	0.10
Chloride	50.6	41.2	60.6	44.4
Boron	0.38	0.40	0.34	0.38
pH	7.6	7.7	7.8	7.9

Table 59. Average Concentration (mg/1) of Various Constituents Applied to the Reed Canarygrass Area - 1965-1969

Constituent	Year 1965	1966	1967	1968	1969
Phosphorus	6.935	7.690	7.695	8.450	4.185
Nitrate-N	6.1	7.9	5.2	4.0	2.8
Organic-N*	2.5	7.1	5.1	3.9	2.8
Ammoniacal-N	-	-	-	15.7	13.0
Potassium	20.6	20.4	15.5	16.6	9.8
Calcium	25.3	26.6	22.7	25.8	24.4
Magnesium	14.0	15.7	12.4	13.1	11.3
Sodium	35.7	39.2	35.5	41.0	30.0
Manganese	-	0.06	0.05	0.15	0.07
Chloride	43.8	57.4	52.2	48.0	39.4
Boron	0.36	0.36	0.33	0.40	0.23
pH	7.6	7.9	7.8	7.7	7.8

*Values for 1965-1967 include ammoniacal nitrogen. These are understated due to loss of undetermined amounts of ammoniacal nitrogen during analytical procedure. Method of analysis changed in 1968.

Table 60. Total Amounts (Pounds Per Acre) of Various Constituents in Sewage Effluent Applied to the Rotation Crops at Rates of One and Two Inches Per Week - 1963-1969

	Amounts Applied (lb/a)									
	1963		1964		1965		1966		1967	
Constituent	1	2	1	2	1	2	1	2	1	2
Phosphorus	52.64	105.71	64.45	127.78	41.46	91.14	43.28	77.87	27.92	76.15
MBAS	17.24	34.80	10.99	23.03	7.16	12.88	2.39	5.22	1.45	3.40
Nitrate-N	31.0	63.1	111.4	206.4	41.4	77.5	58.7	116.0	30.5	59.5
Organic-N*	39.7	79.4	27.7	41.9	17.1	32.8	47.1	66.7	23.6	47.1
Potassium	93.0	182.7	122.6	228.8	130.8	270.7	149.4	278.4	104.2	210.7
Calcium	176.2	351.3	266.3	523.4	163.0	332.5	218.2	419.1	128.0	256.0
Magnesium	100.6	206.6	143.6	286.5	88.0	184.0	143.6	266.8	64.0	138.2
Sodium	250.1	510.0	240.8	511.4	236.6	469.2	300.2	559.7	223.8	453.2
Manganese	**	**	**	**	**	**	0.6	1.2	0.9	1.4
Chloride	236.0	477.4	299.1	581.7	280.6	575.6	394.4	745.4	276.9	509.8
Boron	**	**	3.0	6.0	2.1	4.2	2.6	5.2	2.4	4.6
Inches of Effluent	24	48	33	66	29	58	32	64	26	52

*Values included ammoniacal nitrogen. For the period 1965-1967 values are underestimated due to loss of undetermined amounts of ammoniacal nitrogen during sample analysis. Method of analysis changed in 1968.

**Values not determined.

Table 60. (continued)

Constituent	1968 1	 2	1969 1	 2
Phosphorus	24.22	54.40	16.94	47.55
MBAS	2.28	5.20	2.08	3.94
Nitrate-N	21.1	37.7	21.0	37.3
Organic-N	13.1	34.4	28.3	34.8
Ammoniacal-N	58.0	132.3	41.3	92.8
Potassium	75.7	155.0	55.1	100.1
Calcium	94.7	183.1	125.4	232.0
Magnesium	48.0	94.2	63.1	118.2
Sodium	169.5	370.0	186.7	382.8
Manganese	1.6	1.6	0.4	0.7
Chloride	229.4	373.0	219.8	321.3
Boron	1.7	3.6	1.2	2.8
Inches of Effluent	20	40	16	32

Table 61. Total Amounts (Pounds Per Acre) of Various Constituents Applied to Reed Canarygrass Receiving Two Inches of Sewage Effluent Weekly - 1965-1969

Constituent	Year				
	1965	1966	1967	1968	1969
Phosphorus	125.7	135.9	163.9	187.6	94.8
Nitrate-N	110.6	139.6	110.7	88.8	63.4
Organic-N*	45.3	125.5	108.6	86.6	63.4
Ammoniacal-N	-	-	-	348.6	294.6
Potassium	373.4	360.5	330.1	368.6	222.0
Calcium	458.6	470.1	483.5	572.9	552.8
Magnesium	253.8	277.5	264.1	290.0	256.0
Sodium	647.1	692.8	756.1	910.4	682.0
Manganese	-	1.1	1.1	3.3	1.6
Chloride	794.3	1014.9	1112.8	1065.8	892.3
Boron	6.5	6.4	7.7	8.9	5.2
Inches of Effluent	80	78	94	98	100

*Values for 1965-1967 include ammoniacal nitrogen. These are understated due to the loss of undetermined amount of ammoniacal nitrogen during analytical procedure. Method of analysis changed in 1968.

Table 62. Renovation Efficiency (Percent) of Crops at One and Two Inch Per Week Applications - 1963

	Crop and Inches of Effluent Applied Per Week									
	Red Clover		Alfalfa		Corn Grain		Wheat Grain		Wheat Straw	
Nutrient	1	2	1	2	1	2	1	2	1	2
Nitrogen	*	*	*	*	174.5	89.5	91.9	59.6	13.8	11.5
Phosphorus	49.1	22.9	43.6	30.2	51.9	31.0	30.5	19.3	2.5	2.3
Potassium	281.0	130.0	176.7	124.6	24.5	18.1	12.4	6.3	11.6	10.1
Calcium	73.0	34.7	29.1	13.3	0.2	0.1	0.8	0.5	2.0	1.4
Magnesium	21.8	10.7	11.1	7.2	7.6	4.6	4.0	2.6	1.1	0.7

*Not computed for legumes because of unknown contribution from symbiotic nitrogen fixation.

Table 63. Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Applications - 1964

	Crop and Inches of Effluent Applied Per Week							
	Red Clover		Corn Grain		Corn Stover		Oat Grain	
Nutrient	1	2	1	2	1	2	1	2
Nitrogen	*	*	76.4	52.0	59.7	43.6	31.1	20.6
Phosphorus	52.0	24.1	20.9	10.2	13.3	20.1	27.7	11.1
Potassium	260.6	121.6	24.7	12.0	165.1	99.3	22.3	8.3
Calcium	44.2	15.4	1.9	0.9	23.8	12.4	2.1	0.9
Magnesium	28.2	10.8	4.9	2.3	22.8	11.5	4.9	2.0
Chloride	33.9	19.0	1.2	0.5	10.4	4.8	1.4	0.3
Boron	9.0	5.0	1.3	1.0	1.7	1.7	1.0	0.7

*Not computed for legume of unknown contribution from symbiotic nitrogen fixation.

Table 64. Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Applications - 1965

	Crop and Inches of Effluent Applied Per Week									
	Alfalfa		Corn Grain		Corn Silage		Oat Grain		Oat Straw	
Nutrient*	1	2	1	2	1	2	1	2	1	2
Nitrogen*	**	**	165.6	88.1	183.6	99.8	87.7	32.4	28.9	5.8
Phosphorus	63.6	38.7	78.0	40.5	38.9	21.8	26.3	11.5	15.2	8.4
Potassium	188.5	118.7	26.1	13.3	61.9	40.2	11.4	5.1	88.9	39.5
Calcium	32.1	19.2	0.6	0.9	17.1	8.3	1.4	0.6	12.7	5.9
Magnesium	17.9	10.7	11.2	6.1	17.3	8.2	3.6	1.6	6.1	2.8
Chloride	37.9	22.8	0.9	0.3	10.3	5.8	0.8	0.4	21.7	13.5
Boron	7.6	4.8	1.0	0.5	1.9	1.0	0.5	0.2	1.4	0.5

*Values are overestimated due to the loss of undetermined amounts of ammoniacal nitrogen in effluent sample analysis.

**Not computed for legume because of unknown contribution from symbiotic nitrogen fixation.

Table 65. Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Applications - 1966

Nutrient	Crop and Inches of Effluent Applied Per Week					
	Corn Silage		Corn Grain		Alfalfa	
	1	2	1	2	1	2
Nitrogen*	115.3	77.8	102.1	69.0	**	**
Phosphorus	64.9	50.8	64.4	51.0	59.6	37.9
Potassium	65.9	48.9	16.2	10.4	151.7	89.8
Calcium	13.0	7.7	***	***	24.5	11.5
Magnesium	13.2	8.6	6.5	4.1	10.8	6.3
Chloride	9.5	6.2	0.7	0.6	21.7	9.5
Sodium	0.8	0.4	0.1	0.1	0.6	0.3
Boron	2.0	1.0	***	***	4.0	2.0

*Values are overestimated due to undetermined loss of ammoniacal-N in effluent sample analysis.

**Not determined because of unknown contribution from symbiotic nitrogen fixation.

***Not computed because constituent was not determined.

Table 66. Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Application - 1967

	Crop and Inches of Effluent Applied Per Week									
	Corn Pa. 602-A*				Corn Grain Pa. 444				Alfalfa	
	Silage		Grain		19" Row Spacing		38" Row Spacing			
Nutrient	1	2	1	2	1	2	1	2	1	2
Nitrogen**	175.0	105.2	162.2	77.5	136.4	75.5	112.6	63.8	***	***
Phosphorus	80.6	39.5	86.0	34.4	73.1	33.0	66.3	26.1	76.3	31.9
Potassium	105.8	60.6	21.9	10.3	15.9	9.2	13.3	7.1	173.8	99.2
Calcium	16.3	7.9	****	****	****	****	****	****	24.8	12.5
Magnesium	24.2	12.7	11.1	5.1	10.2	5.1	10.0	4.2	17.2	9.0
Chloride	12.8	7.2	1.0	0.2	0.9	0.2	0.7	0.1	28.0	18.6
Sodium	0.62	0.38	0.04	0.02	0.03	0.04	0.04	0.02	0.52	0.28
Boron	2.5	1.5	0.4	0.2	0.4	0.2	0.4	0.2	2.9	1.7

*Nineteen inch row spacing.

**Values are overstated due to the loss of undetermined amounts of ammoniacal nitrogen in effluent sample analysis.

***Not computed for legume because of unknown contribution from symbiotic nitrogen fixation.

****Not computed because tissue content was less than 0.10% Ca, but generally was less than 5.3% renovation efficiency.

Table 67. Renovation Efficiency (Percent) of Crops at One and Two Inches Per Week Application - 1969

Nutrient	Crop and Inches of Effluent Applied Per Week			
	Corn Silage Pa. 890-S		Corn Silage Pa. 602-A	
	1	2	1	2
Nitrogen	248.2	142.3	285.6	120.1
Phosphorus	204.8	90.6	177.7	123.4
Potassium	218.1	146.4	263.9	96.9
Calcium	24.9	12.2	33.1	7.0
Magnesium	35.4	21.2	35.2	15.5
Chloride	21.8	16.0	21.8	10.5
Sodium	0.81	0.44	1.04	0.48
Boron	4.9	2.5	6.5	1.8

Table 68. Renovation Efficiency (Percent) of Reed Canarygrass at Two Inches of Sewage Effluent Application - 1965-1969

Nutrient	Year 1965	1966	1967	1968	1969
Nitrogen*	226.4	102.7	150.0	68.2	75.8
Phosphorus	31.8	24.6	34.2	25.2	49.0
Potassium	86.2	70.0	103.1	68.6	96.6
Calcium	13.5	6.1	13.4	7.1	8.8
Magnesium	11.7	6.9	15.4	9.6	13.9
Chloride	23.6	12.2	18.0	15.9	19.5
Sodium	0.7	0.2	0.6	0.3	0.6
Boron	1.0	0.9	1.3	0.6	1.9

*Values are overstated in 1965-1967 due to loss of ammoniacal nitrogen during effluent sample analysis. Method of analysis corrected in 1968.

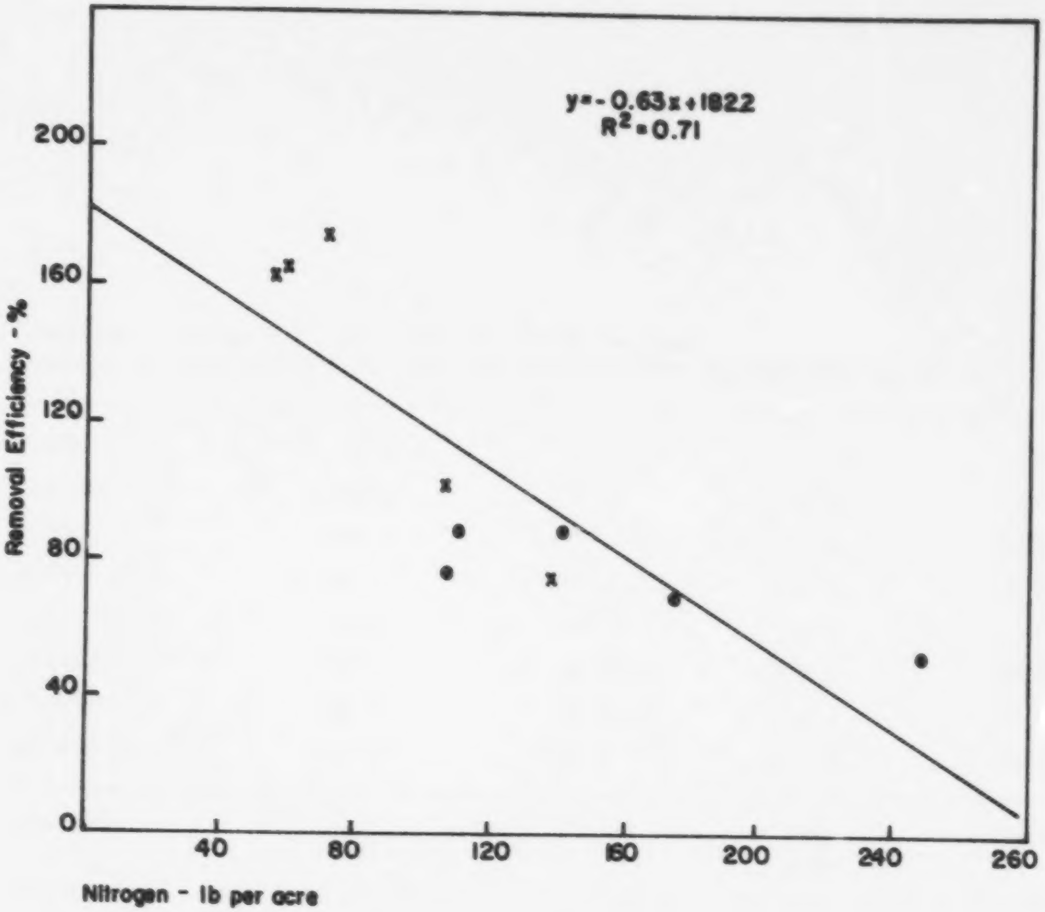

Figure 42. Regression of Removal Efficiency on Nitrogen Loading.

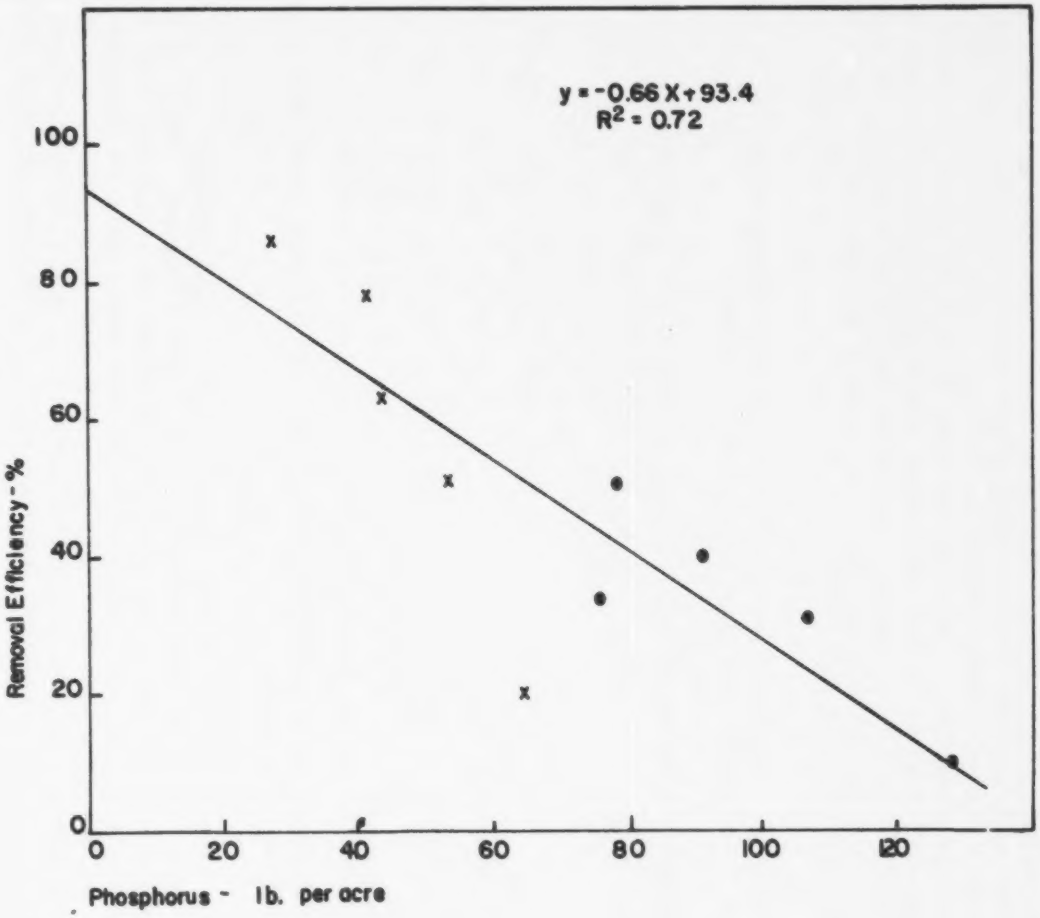

Figure 43. Regression of Removal Efficiency on Phosphorus Loading.

is split into 20 to 50 doses at weekly intervals hence the larger total amount never reaches a toxic level. However, if the small incremental amounts accumulated, excessive quantities of boron might become toxic to vegetation. A later section will describe the investigation of the boron relationships in greater detail.

The removal of nutrients in the harvested crops was computed as a renovation efficiency in Tables 62 through 68. Discussion will be focused on the two key eutrophic nutrients, N and P. The removal efficiencies of the individual crops in comparable years are summarized in Table 69. On the rotation crop area the highest removal efficiency for nitrogen was obtained with silage corn and for phosphorus with grain corn. Grain corn was substantially better than oats in removing both nitrogen and phosphorus. Generally as the nutrient load increased the removal efficiency decreased. This is obvious within years by comparing the 1-inch and 2-inch treatment values and is also shown when comparing the same crop in different years as indicated in Figures 42 and 43. These linear regressions of amount of nutrient load with removal efficiency were significant at the 0.001 level. The R^2 value for the regression equations were 0.71 for nitrogen and 0.72 for phosphorus.

Table 69. Average Removal Efficiencies of Various Crops for Nitrogen and Phosphorus in Comparable Years

	Removal Efficiency - %							
	1965-1967				1964-1965			
	N		P		N		P	
Crop	1"	2"	1"	2"	1"	2"	1"	2"
Alfalfa	*	*	66.5	36.2				
Corn-Grain	143.3	78.2	76.1	42.0	121.0	70.0	49.5	25.3
Corn-Silage	158.0	94.3	61.5	37.4				
Oats-Grain					59.4	26.5	27.0	11.3

*Not computed because of unknown inputs of nitrogen from symbiotic nitrogen fixation.

The inherent capacities of the individual crops can also be compared by examining the absolute amounts of N and P removed. These data are expressed in Table 70 as amounts removed per acre per crop year and indicate the obvious superiority of reed canarygrass in removing both N and P. Oats were least effective and corn silage was better than corn grain, particularly with respect to N, and also with respect to P at the higher nutrient loading level. The legume hays were just

Table 70. Amounts Removed in Harvested Crops Per Acre Per Crop Year on Wastewater Treated Areas - 1963-1969

	No. of Harvest Years	Nitrogen		Phosphorus	
		1"	2"	1"	2"
Alfalfa Hay	3	247.7	220.7	25.2	31.4
Red Clover Hay	2	252.7	227.0	30.3	27.0
Corn	5	100.9	111.2	24.8	28.7
Corn Silage	4	145.7	140.6	24.2	36.5
Oats	2	46.8	45.9	14.9	12.5
Reed Canarygrass	5		333.0		44.6

about as effective as corn in removing phosphorus on the wastewater treated areas. Nitrogen removals in the legumes were higher than in corn grain or silage but it is not known what fraction may have been provided by symbiotic nitrogen fixation. It is known that high levels of nitrogen fertilization suppress nodulation and presumably symbiotic fixation by the nodule bacteria. Hence the legumes may be using a substantial part of the nitrogen added in the wastewater. Water quality data in the wastewater treated plots indirectly indicate that the legume hays were utilizing the added nitrogen, inasmuch as the nitrate content in the soil water was lower at sampling sites located in the legume hay strips than in the corn strips.

Removals of potassium and chloride were greatest with the legume hays, slightly less with corn silage and substantially less with both grains, corn and oats. Removals of potassium by the legumes is so great that future fertility management might require additions of fertilizer potash to maintain good yields. Removals of potassium and chloride were highly correlated but potassium was removed in greater quantities in all crops. The quantities of both cations and anions removed by the legumes and silage corn result in a substantial desalination of the wastewater, equivalent to approximately 20-25% of the cations and anions present in the wastewater.

Boron although added in the smallest total amounts was also removed in small amounts. The removal efficiency of the non-legume crop for boron was poor, and even the legumes did not reach 10%. The lowest average removal efficiencies occurred with sodium. Sodium was not only strongly excluded from the whole plant, it was even more severely excluded from the grain. This means that most of the sodium will either be retained by the soil through cation exchange reactions or move into the groundwater.

Nutrient additions to the reed canarygrass were 50% to 200% greater than on the crop rotation area because of the larger amounts of effluent applied. As a consequence removal efficiencies are not as great but total amounts of nutrients removed were all substantially higher. In 1969 the 354 pounds of nitrogen removed was equivalent to a removal efficiency of 75.8% whereas the 236 pounds of nitrogen removed by silage corn that year was equivalent to a removal efficiency of 142.3%. In that year the reed canarygrass area received 421 pounds of nitrogen in 100 inches of wastewater throughout the year while the silage corn was receiving only 165 pounds of nitrogen from mid-May to mid-September (16 weeks). The comparative capacities of reed canarygrass and corn silage for removing nitrogen and phosphorus are shown in Figures 44 and 45.

In conclusion it can be stated that all harvested crops make a significant contribution to renovating the wastewater. The fate of the nutrients not absorbed and removed in the harvested crops will be described in subsequent sections.

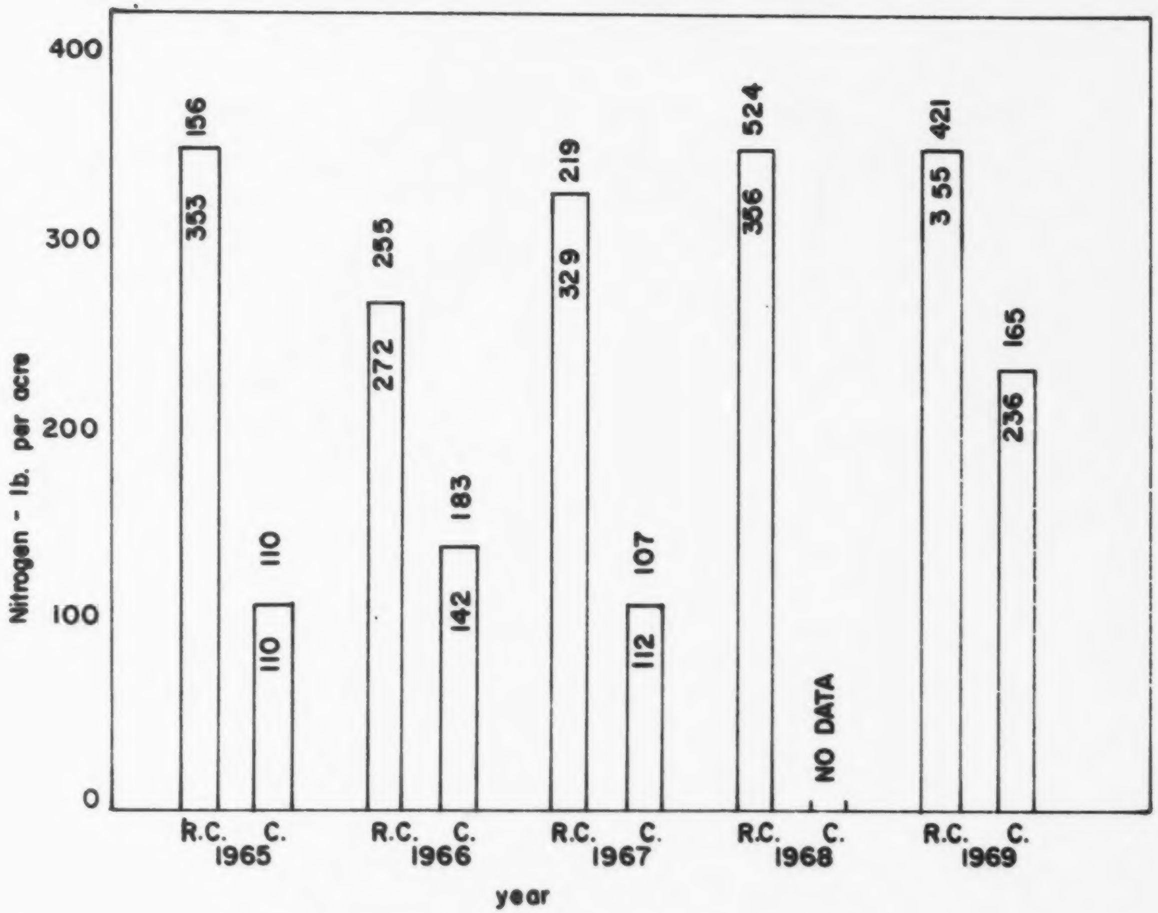

Figure 44. Nitrogen Added in Applied Sewage Effluent and Removed in Harvested Reed Canarygrass and Silage Corn.

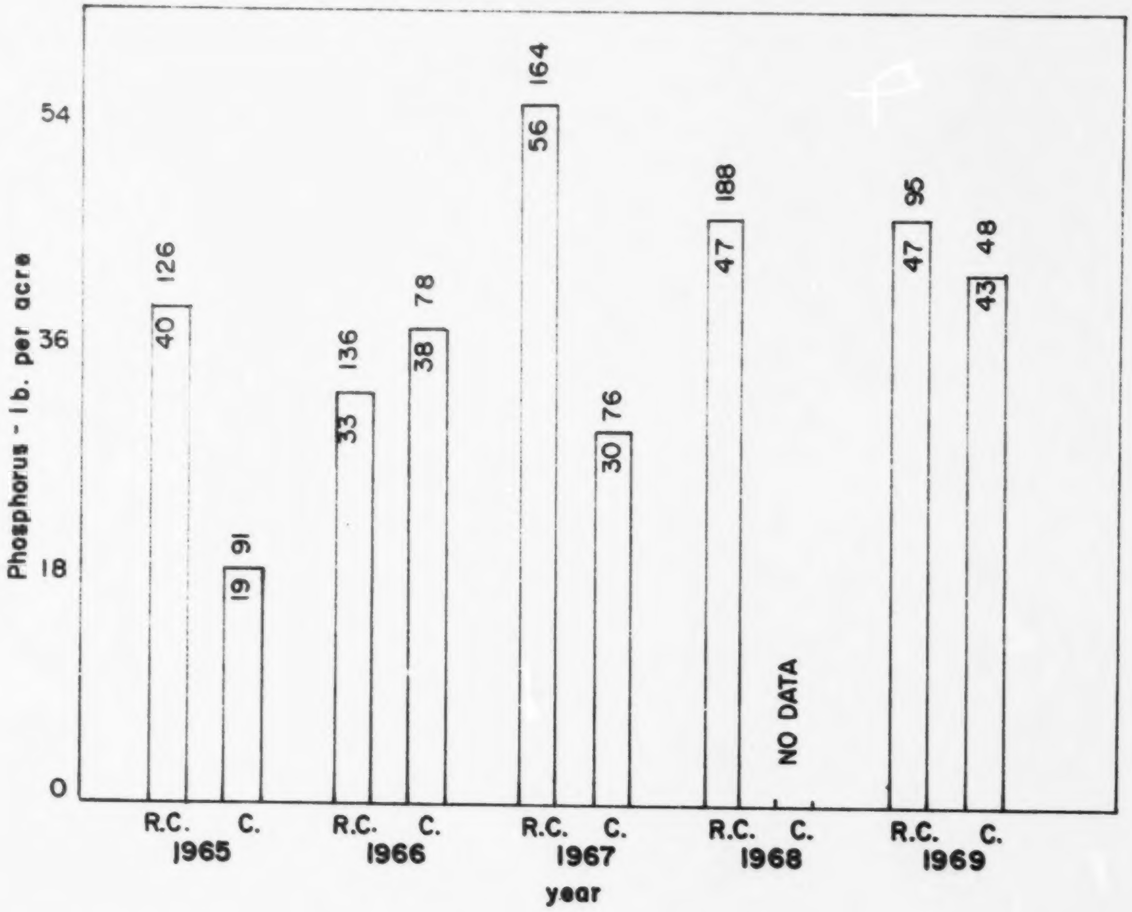

Figure 45. Phosphorus Added in Applied Sewage Effluent and Removed in Harvested Reed Canarygrass and Silage Corn.

Soil Percolate Water Quality

Previous Studies. It has been indicated that substantial amounts of various constituents in the applied wastewater were removed in harvested crops and hence changes in the chemical quality of the percolating wastewater can be expected from operation of this segment of the living filter system alone. In addition it can be expected that other biological and physico-chemical reactions could influence the final equilibrium concentrations of the various chemical elements in the percolating water which is derived from either the applied wastewater or from natural precipitation.

A review of the literature indicates that many of the earlier studies of water quality changes in passing through soil were with systems involving raw sewage or primary effluents in infiltration basins or spreading basins with relatively high loading rates. Baars (31) reported that in Europe effluent from surface infiltration basins commonly formed the source of recharge for the ground water supply. In a study in the Netherlands he noted that the percolate from the basins was significantly lower in nitrate because of denitrification. Although suspended matter was reduced by 100 percent, chloride, bicarbonate and hardness showed little change.

In the United States, one of the earliest instances of the application of sewage effluent to the soil was described by Laverty (32). He states that the spreading of wastewater by means of ditches and canals began in 1916 in the San Gabriel Valley, California in order to supplement the ground water. More detailed studies were not made until 1930 when Goudey (33) investigated the spreading, on sand beds, of sewage plant effluent. It was found that the quality of the ground water was not significantly affected after the percolate had travelled 25 feet. More recently, Stone and Garber (34, 35) reported that in sewage effluent percolated through seven feet of soil, nitrate, phosphate, potassium and boron were measurably removed. On the other hand, there were insignificant changes in concentration of such constituents as calcium, magnesium, sodium and chloride. Similar results were obtained in a different study (36) after the effluent percolated through 13 feet of soil. Throughout this depth nitrates however steadily increased, phosphorus disappeared within the upper foot and potassium decreased by 50 percent below seven feet.

In a study involving five California soils (37) it was found that after an initial decrease attributed to dilution, the concentrations of magnesium, sodium, ammonia-nitrogen, and phosphate increased and, at a depth of three feet, approached the levels of the applied sewage. At the same depth calcium in the percolate increased two to five times; chloride remained essentially constant while nitrate decreased to trace amounts from an original concentration that averaged 0.8 ppm.

After irrigating reed canarygrass with effluent from a meatpacking plant, Henry et al. (24) noted that calcium, potassium and magnesium increased in the percolate at a depth of four feet. They attributed this to replacement of these ions on the exchange complex by sodium which was present in the effluent at a much higher concentration (680 ppm). There was little change in the concentrations of sodium and chloride although phosphorus was sharply reduced.

Greenberg and Gotaas (38) reported only few chemical changes in final sewage effluent after it had percolated 13 feet. Calcium, magnesium, sodium and potassium did not change significantly. Ammonia-nitrogen and phosphate were entirely removed within the upper foot but nitrate and organic nitrogen increased. They concluded that nitrification was responsible for the increase in nitrate concentration (24 ppm to 68 ppm) and conceded that were it not for dilution by the ground water, the percolate would have been unfit for drinking according to the standards set by the United States Public Health Service (39).

Investigations by Greenberg and McGauhey (40) and by Greenberg and Thomas (41) produced similar results except that potassium, in this case, decreased by 50 percent, chloride remained unchanged, but nitrate-nitrogen increased by several hundred percent evidently at the expense of ammonia-nitrogen and nitrite-nitrogen.

As the impact of pollution and the involvement of ABS became more evident and as methods for its determination were developed, ABS also became a constituent of interest to those studying the chemical changes of percolating effluent.

The removal of ABS from percolating wastewater was effected by adsorption by the soil and by degradation by soil microorganisms. In column studies, Klein et al. (42) found that ABS was adsorbed mostly in the upper 2.5 cm of soil. Biological degradation was also highest in this zone possibly on account of the favorable oxygen status that existed. They also found that ABS was rapidly desorbed from the soil to an extent of 80 percent when leached with ABS-free water. An evaluation of the relative importance of adsorption and degradation of ABS in the renovation process has not met with agreement. The authors found that biological degradation played a minor role in the removal of ABS from the percolating effluent. On the other hand, Robeck et al. (43) found that the reduction of ABS was due almost entirely (97 percent), to degradation. The mode of degradation of ABS has been studied by McKinney and Symons (44). They postulated that the incomplete degradation of ABS was due to the presence of a quaternary carbon atom within the molecule. Where this was absent, as in LAS, biological degradation would approach completion. Evidence in support of this was later cited by Sawyer and Ryckman (45).

The removal of ABS from percolating wastewater has been undoubtedly, adequate. Highly treated, activated-sludge sewage effluent was used in a reclamation study by McKee and McMichael (46). At a depth of eight feet they found that the percolate showed an increase in calcium and nitrate concentrations. Magnesium and chloride remained essentially constant but surfactant (ABS) along with sodium, potassium, ammonium and phosphate decreased significantly.

A high degree of renovation of sewage plant effluent was reported by Pennypacker et al. (47) in the irrigation of forest land. At application rates of one inch per week and two inches per week. The removal of ABS by the forest floor (two-inch depth) amounted to 86 percent and 65 percent respectively. However, at a depth of one foot the removal was 95 percent and 98 percent respectively. In the forest floor, nitrate-nitrogen increased three-fold but at a depth of one foot it was reduced by 68-82 percent. Other removals at this depth included organic-nitrogen by 75-86 percent and phosphorus by 99 percent. Chloride was slightly lower in the percolate. The authors further noted that various constituents in the effluent tended towards equilibrium at certain depths. For example, phosphorus and potassium equilibrated within the upper foot while the concentrations of ABS, nitrate-nitrogen, calcium, magnesium, sodium and chloride leveled off at four feet. Laverty et al. (48) also reported that intermittent spreading of primary sewage effluent improved its quality prior to injection into recharge wells. Nitrate, phosphorus and ABS decreased but chloride was not removed.

These studies on percolating effluent have indicated certain trends with regard to chemical changes in the effluent. Apart from potassium, the cations generally showed little change. In the case of anions, ABS and phosphate were sharply reduced while chloride which shows almost no tendency towards ion adsorption by soil, remained unchanged. Nitrate, however, depending on the conditions prevailing in a particular system may either increase or decrease with the depth of percolation.

Procedures. Samples of water percolating through the soil profile were secured using suction lysimeters[1] in order that samples might be collected whether the percolating water was moving downward under tension gradients or in saturated flow.

Each lysimeter, as illustrated in Figure 46 consists of a porous ceramic cup (1 7/8 in. O.D. x 2 7/8 in. long) cemented to a plastic tube (1 7/8 in. O.D.) at the lower end. The upper end of the plastic tube is sealed with a rubber stopper (No. 8) through which passes a short length of copper tubing (3/8 in O.D.). A short length of thick-walled rubber tubing bearing a Hoffman screw clamp is fitted over the

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[1] Obtainable from Soilmoisture Equipment Company, 3005 De La Vina St., Santa Barbara, California.

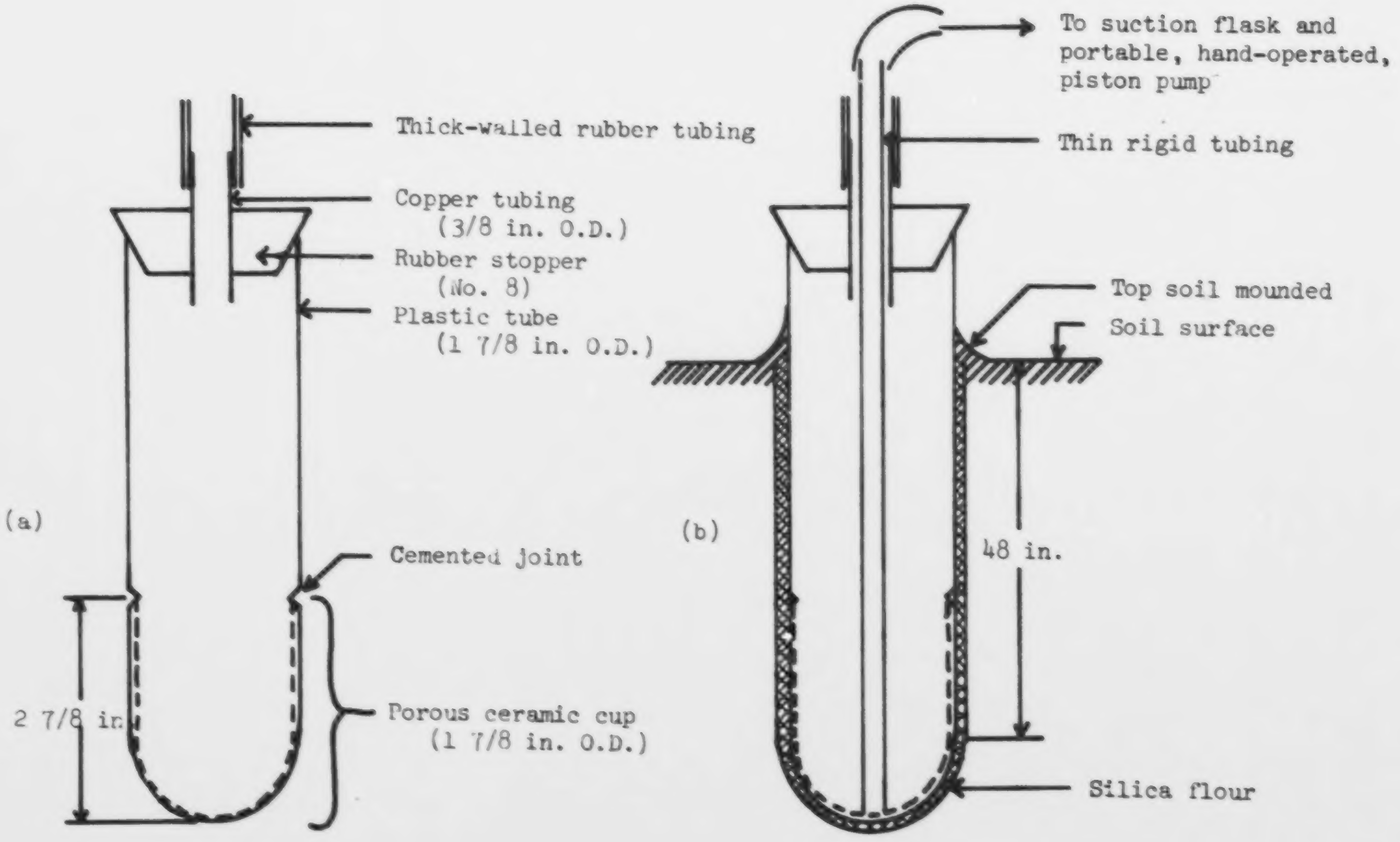
Thick-walled rubber tubing
Copper tubing (3/8 in. O.D.)
Rubber stopper (No. 8)
Plastic tube (1 7/8 in. O.D.)
(a)
Cemented joint
2 7/8 in
Porous ceramic cup (1 7/8 in. O.D.)
To suction flask and portable, hand-operated, piston pump
Thin rigid tubing
Top soil mounded
Soil surface
(b)
48 in.
Silica flour

Figure 46. Diagram of (a) Suction Lysimeter with Single Hole Stopper Assembly and (b) Lysimeter Installed at Depth of 48 Inches with Tubing Inserted to Remove Sample

end of the copper tubing protruding above the stopper.

Prior to installation each lysimeter was washed several times with dilute HCl (approximately 0.01N) and then rinsed free of chloride with distilled water. This preliminary washing was carried out because it was previously noticed that a rather alkaline reaction (pH 9) was imparted to distilled water flowing into the porous ceramic cup, probably on account of dissolution of bases in the walls of the cup itself. Washing was effected by placing the lower end of the lysimeter in the dilute acid and partially evacuating the chamber, thus allowing the liquid to flow through the walls of the cup.

The lysimeters were installed at three depths, namely, 6 inches, 24 inches and 48 inches. Installation in the corn rotation areas was completed prior to start of irrigation in 1965. Installation in the reed canarygrass area was completed in the summer of 1965. Installation, as illustrated in Figure 46, was carried out with the help of a screw-type auger that made a hole 1 3/4 inches in diameter. The sides of each hole were smoothed by forcing a two inch aluminum pipe down to the required depth, with allowance being made for a 1/2 inch layer of silica flour[2] on the bottom of the hole. After the lysimeter was inserted in the hole more silica flour was packed around its entire length. Finally, top soil was packed around the lysimeter at the soil surface.

In operating the suction lysimeter, a portable, hand-operated piston pump was attached to the plastic tube via the thick-walled rubber tubing, the chamber partially evacuated to 25 inches of mercury and the screw clamp tightened. The hydraulic gradient across the porous cup induces flow of water into the chamber until tension forces are balanced.

To remove the samples, the clamp was loosened, releasing the vacuum, and suction was applied through a suction flask to a length of copper or rigid plastic tubing inserted to the bottom of the lysimeter. The total volume of the sample was measured and the entire sample, if less than one liter, or a one-liter subsample was poured into polyethylene bottles. Samples were collected on a weekly basis throughout each year regardless of whether or not wastewater was applied. During the period of application, the collection was made, generally within 24 hours of the end of each weekly application.

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[2] Obtainable from Pennsylvania Glass Sand Corporation, Mapleton, Pennsylvania

Suction Lysimeter Data

The mean annual concentration of various constituents in suction lysimeter samples at three depths in the crop rotation area (Agronomy Area A-0, A-1 and A-2) are given in Tables 71 through 83 on pages 166 to 178. Similar data for the reed canarygrass area (Agronomy Area A-3) occur in Table 84 on page 179.

The significance of the main effects in the corn rotation area for treatments (0, 1 and 2 inches per week) within depths (6", 24" and 48") and within years (1965-1969) is summarized in Tables 71 to 83 on pages 166 to 178 and the years effect within treatments and within depths in Tables 85 to 97 on pages 180 to 192.

The data in Table 71 indicate that phosphorus concentration decreases drastically between the upper six inches and the 24-inch depths on all areas. At the 6-inch depth, concentrations in the 2-inch treatment area were significantly greater than in both the control area (0-inch) and the one-inch treatment area (Figure 47). At the 24-inch depth differences in phosphorus concentration between wastewater treatments was non-significant in three of the five years (Table 71 and Figure 48). At the 48-inch depth the differences were unrelated to wastewater treatment or non-significant (Table 71 and Figure 49). The year effects (Table 85) were erratic. There was a general tendency on the wastewater treated areas for phosphorus concentration to increase through 1967, levelling off or decreasing in 1968 and 1969.

The nitrate nitrogen with its greater chemical mobility shows no consistent depth pattern and an erratic wastewater treatment pattern, particularly at the six inch depth (Table 72). The years effect within wastewater treatments and within depths (Table 86) was highly significant for all depths and appears to be a reflection of the extent to which corn, either grain or silage, rather than alfalfa-grass hay occupied the treatment area. In the period 1965-67 corn occupied 28% of the area, in 1968 and 1969 it was 100% but with a heavy weed infestation in 1968 and weed-free in 1969. The nitrate-nitrogen values at the 48-inch depth (Figure 50) might be regarded as the break-through nitrate values which have escaped the biological removal zone and hence might be expected to reach the groundwater. These values in the 1965-67 period ranged from 3.4 to 5.3 mg NO_3N per liter in the control area, from 3.8 to 8.2 in the 1-inch wastewater area and from 7.0 to 9.7 in the 2-inch wastewater area. In 1968 when heavily weed-infested corn occupied 100% of the area the nitrate nitrogen values at the 48-inch depth were 4.3, 5.8 and 9.6 mg NO_3-N per liter, respectively in the control, 1-inch and 2-inch treatment areas. In 1969 when weed-free corn occupied 100% of the area the nitrate values were 9.3, 7.7 and 14.0 mg NO_3-N per liter, respectively, for the same treatment areas. The value of 14.0 mg, in 1969, exceeds the recommended limit of the Public Health Service, 10 mg NO_3-N per liter.

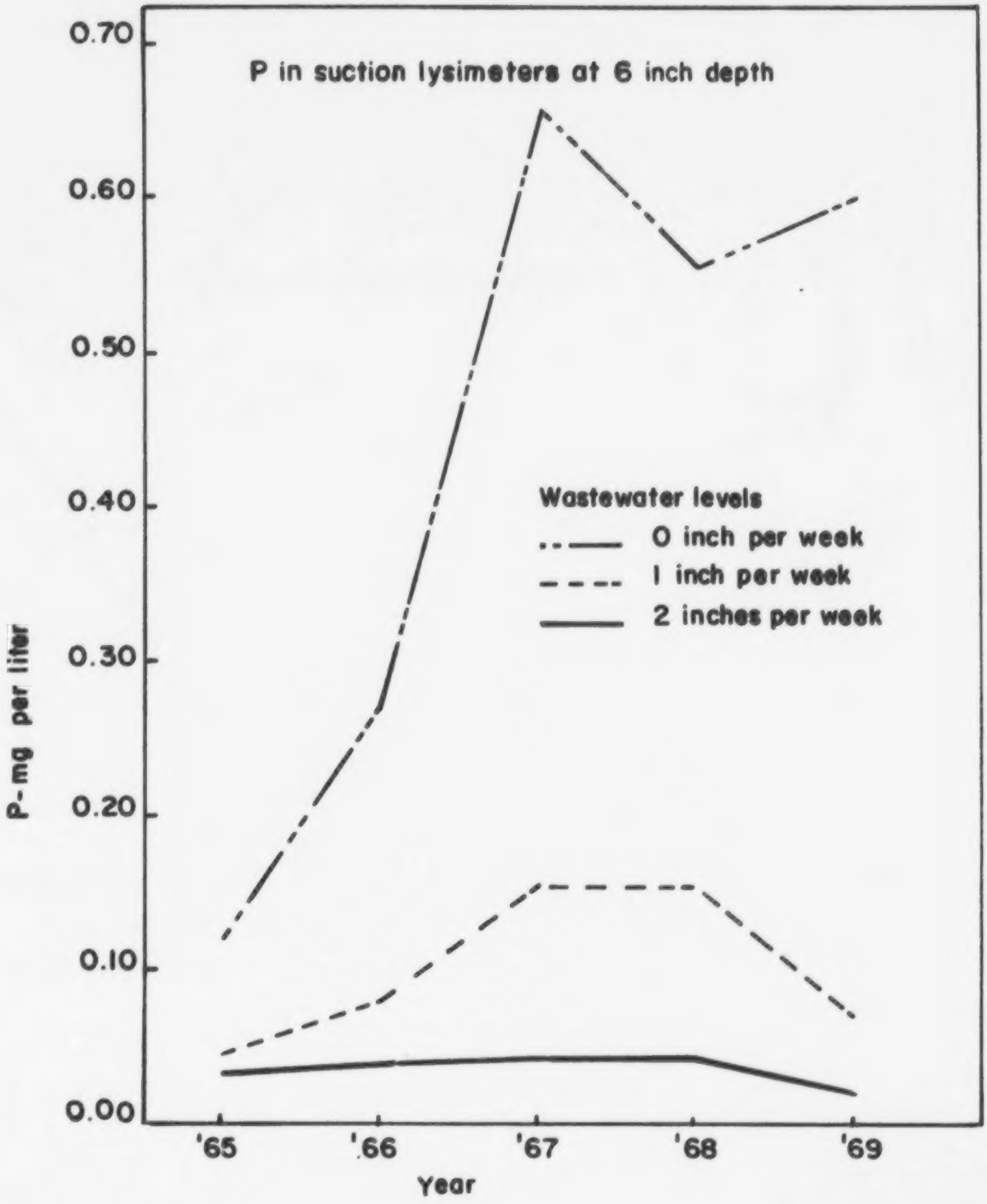

Figure 47. Mean Annual Phosphorus Concentration in Suction Lysimeters at the Six Inch Depth in the Corn Rotation Area Receiving 0, 1, and 2 Inches of Wastewater at Weekly Intervals, Apr. - Nov., 1965-1969.

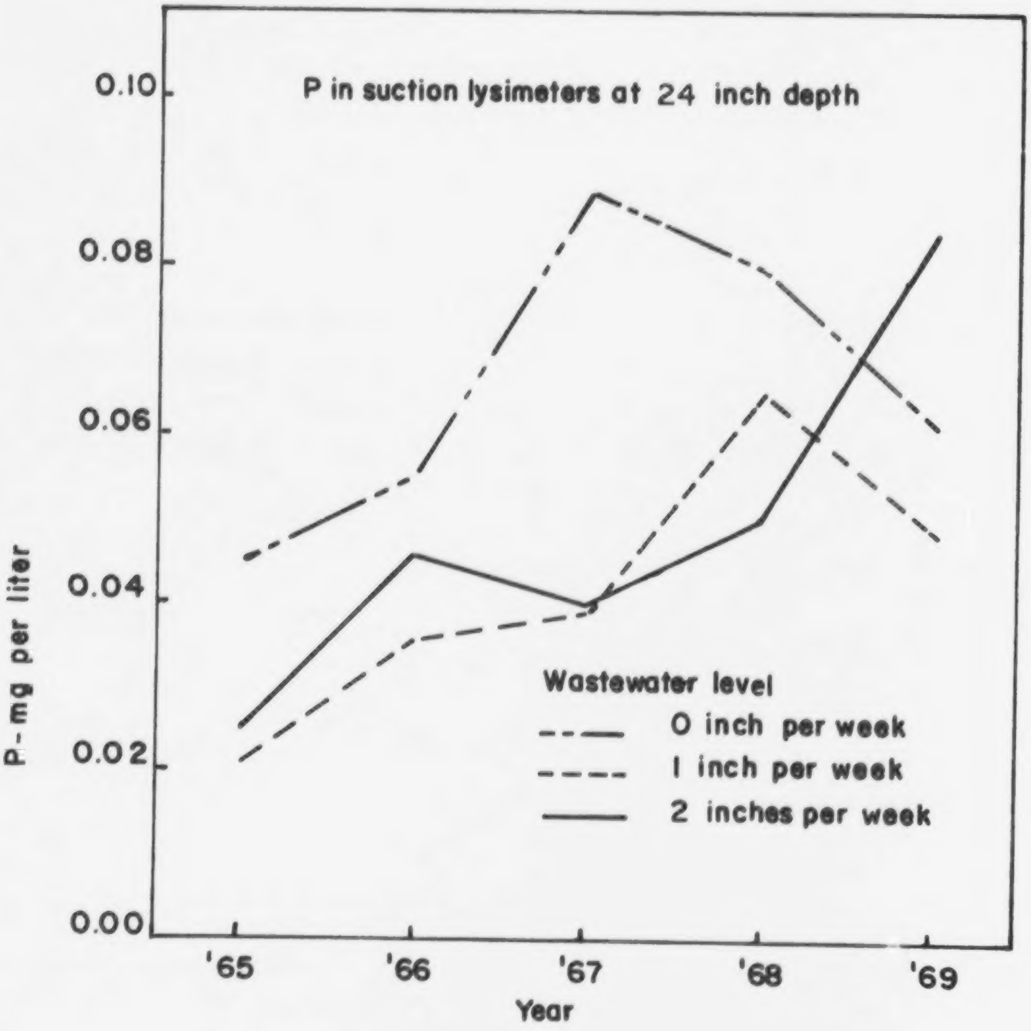

Figure 48. Mean Annual Phosphorus Concentration in Suction Lysimeters at the 24-Inch Depth in the Corn Rotation Area Receiving 0, 1, and 2 Inches of Wastewater at Weekly Intervals, Apr. - Nov., 1965-1969.

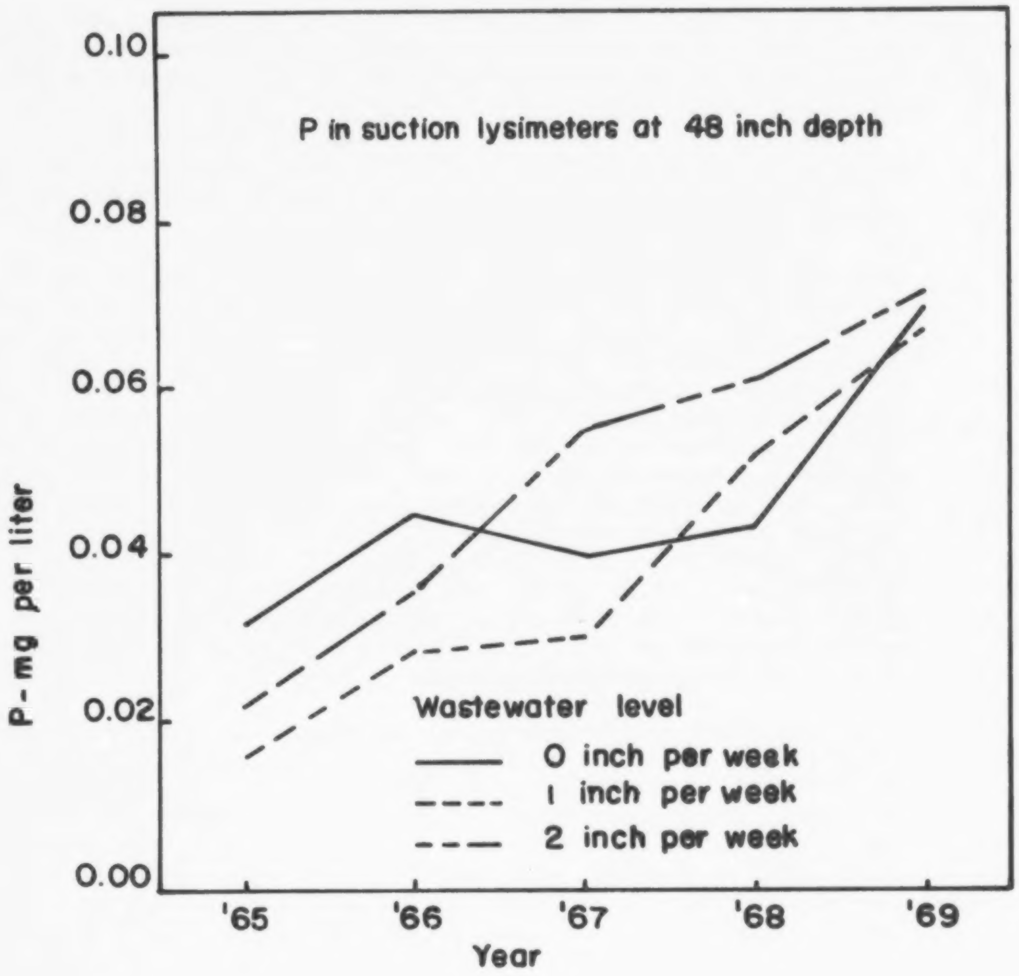

Figure 49. Mean Annual Phosphorus Concentration in Suction Lysimeters at the 48-Inch Depth in the Corn Rotation Area Receiving 0, 1, and 2 Inches of Wastewater at Weekly Intervals, Apr. - Nov., 1965-1969.

It is probable, therefore, that corn grown without a cover crop on a well drained soil would not be satisfactory for controlling the leakage of nitrate into the groundwater when two inches of treated wastewater is applied weekly. On the other hand corn grown in a no-till sod culture system may do an adequate job.

The data in Table 84 indicate that a perennial grass, reed canarygrass, which received two inches of wastewater weekly, year round, and hence more than twice as much total nitrogen as the corn rotation area, kept the NO_3-N concentration far below the P.H.S. limit. Figure 50 shows the year by year variation of NO_3-N at the 48-inch depth on the corn rotation area and the reed canarygrass area. It is clear that a harvested perennial grass would be advantageous in diminishing nitrate leakage from wastewater treated areas.

Data for kjeldahl nitrogen and ammonium nitrogen (Tables 73, 74, 87, 88) were examined for statistical significance of treatments only in 1968 and 1969. Data for the earlier years was not available for ammonium nitrogen and was unreliable for the kjeldahl nitrogen because of an error in analytical procedure in 1965, 1966 and 1967. The years effects were not examined because only 1968 and 1969 had reliable values. Differences between the wastewater treatments for both kjeldahl nitrogen and ammonium nitrogen were not significant in both 1968 and 1969. The ammonium nitrogen concentration in the lysimeter samples was much lower than concentrations in the applied wastewater. The latter ranged from 5.3 to 15.7 mg NH_4-N per liter whereas the range in the lysimeter samples in the effluent treated plots was 0.41 to 1.08 mg per liter. Thus most of the NH_4-N was either adsorbed on exchange sites, biologically transformed to protein by the microbes and higher plants, or biologically transformed to nitrate.

Potassium which was present in the wastewater in mean annual concentrations ranging from 13.5 to 20.6 mg/1 was substantially decreased in concentration in percolating through the soil. Differences due to the wastewater treatments (Table 75) were non-significant for all years at the 6-inch depth. At the 24-inch and 48-inch depth the concentration in the wastewater areas was significantly greater than in the control only in 1968 and then only at the 5% level of significance. In 1969 the concentration at the 48-inch depth was significantly greater (5% level) in the control than in the 1-inch wastewater treatment but not when compared to the 2-inch treatment. The year effects (Table 89) were erratic at the six inch depth but in all three treatments the potassium concentration at both the 24-inch and 48-inch depths tended to decrease with time.

Calcium concentration in the wastewater also decreased substantially in passage through the soil. Mean annual concentration in the wastewater ranged from 20.2 to 35.6 mg/1 but at the 48-inch depth only from 5.4 to 11.8 mg/1 in the lysimeter samples from the wastewater areas. Differences due to wastewater treatment (Table 75) were generally non-

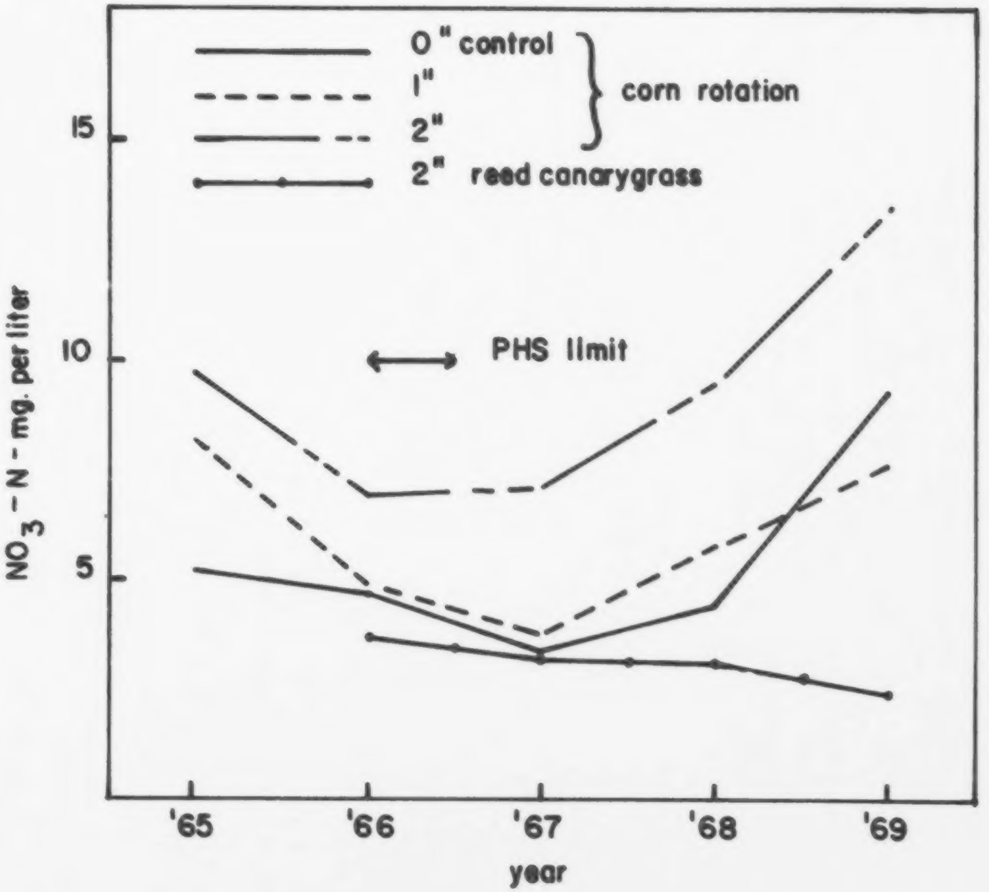

Figure 50. Nitrate-N in Suction Lysimeters at the 48-Inch Depth in the Corn Rotation and Reed Canarygrass Areas.

significant at the 6-inch depth except in 1967 when the 2-inch treatment was significantly greater than the control and in 1967 when the wastewater treatments were significantly less than the control. Concentrations of calcium at the 24 and 48-inch depths in the wastewater treatments were generally higher than in the control in 1965 and 1966 but the differences became erratic in 1967, 1968 and 1969. As with potassium the year effects (Table 90) were erratic at the 6-inch depth but calcium concentration at the 24 and 48-inch depth tended to decrease with time in the 1 and 2-inch wastewater treatments.

Like potassium and calcium, magnesium also decreased in concentration substantially in passing through the soil. Mean annual magnesium concentration in the wastewater ranged from 10.4 to 19.8 mg/1 and from 2.7 to 7.0 mg/1 in lysimeter samples from the 48-inch depth on the wastewater treated areas. Wastewater treatments (Table 77) generally had higher concentrations of magnesium than the control at all three depths. Year effects on the control area were erratic and small (Table 91). On the wastewater treated areas, magnesium concentration in the lysimeter samples tended to decrease with time, particularly at the 24 and 48-inch depths.

The greatest increase in concentration of any constituent as a result of wastewater application occurred with sodium and the differences were highly significant (Table 78). Although the wastewater applications increased the sodium concentration in the soil water 10 to 30 fold it should be noted this concentration was substantially less than the concentration of sodium in the applied wastewater. The latter ranged in mean annual concentration from 32.2 to 52.8 mg per liter whereas the lysimeter samples from the 48-inch depth in the wastewater areas ranged from 19.1 to 32.3 mg per liter. Adsorption on the exchange sites contributed to this decrease whereas uptake by plants was negligible. The years effect (Table 92) was non-significant and variable in the control area and was erratic in the wastewater areas.

The difference in concentration of chloride between the control area and the wastewater treated areas (Table 79) was not as great as with sodium because chlorides were added to the control area with the applied commercial fertilizers which contained potassium chloride. However the differences were highly significant at all depths. The chloride concentration in the lysimeter samples at the 48-inch depth in the wastewater areas although large, ranging from 25.7 to 40.3 mg per liter, were nevertheless smaller than in the applied wastewater, 38.9 to 60.6 mg per liter. Substantial quantities of chlorides were removed in harvested crops and, as will be seen in the section on soil chemical characteristics, significant amounts were adsorbed by the soil. The years effect on chlorides (Table 93) was primarily a decrease with time, showing up more consistently, beginning in 1967.

Manganese concentrations in the lysimeter samples (Table 80) were very low and substantially lower than in the applied wastewater, which had a mean annual range from 0.08 to 0.36 mg Mn per liter. Significant differences found at the 24 and 48-inch depths were expressed as smaller concentrations in the 2-inch wastewater treatment. The years effect was variable (Table 94). In the 2-inch treatment area only one value exceeded the U.S. Public Health Service recommended criteria for drinking water, 0.05 mg Mn per liter. At the 48-inch depth in the control and one-inch treatment areas only the 1969 value did not exceed the P.H.S. value. The mean value over the five-year period at the 48-inch depth was 0.080, 0.060 and 0.042 mg Mn per liter, respectively, for the control, 1-inch and 2-inch wastewater areas.

Although boron was always present in the wastewater at concentrations below the U.S.P.H.S. recommended limit for drinking water it was of particular interest because of its essentiality for plant growth and the narrow range in concentration between essentiality and toxicity which for some crops may be only a difference of 0.5 mg B per liter. Boron concentration in the wastewater has been remarkably constant over the years. The mean annual concentration has ranged from 0.29 to 0.42 mg B per liter. Even this low concentration has been decreased substantially in passing through the soil (Table 81). Concentration at the 48-inch depth in the wastewater areas has ranged from only 0.041 to 0.151 mg B per liter. However even these low values represent a highly significant increase in boron relative to the control area which ranged from 0.018 to 0.038 mg B per liter at the 48-inch depth. In most cases the 2-inch treatment resulted in higher concentrations than the 1-inch treatment. The depth effect was inconsistent in the control area but concentration fairly consistently decreased with depth in the wastewater treated areas. The years effect (Table 95) has been inconsistent on the control and 1-inch areas but concentrations have increased with time on the 2-inch area. In any event,concentrations of boron recharging to the groundwater should not constitute a health hazard.

The slightly alkaline nature of the wastewater, with a mean annual range from pH 7.2 to pH 8.0, would be expected to be diminished in passing through the slightly acid to moderately acid soil profile and such was found to be the case. The highly significant depth effect over all treatments and years summarized in Table 82 is a reflection of the soil profile pH pattern. The only consistent years effect (Table 96) appears to be with the 1-inch wastewater treatment at the 6 and 24-inch depths and involves a decrease in pH with time. This may be due in part to the diminishing hydraulic load, and hence alkaline load, with time in the 1965-69 period on the corn rotation area. The hydraulic load ranged from 29 inches in 1965, 32 inches in 1966, 26 inches in 1967, 20 inches in 1968 to 16 inches in 1969. As a result the inherently acid soil has been able to acidify the percolating wastewater to a greater degree and the mean annual value includes a relatively larger number of samples obtained during the non-irrigation period when slightly acid, poorly buffered rainwater was percolating through the soil.

The MBAS (methylene blue active substance) as a measure of detergent residual is not particularly important from a water quality standpoint at its present levels in the wastewater. The mean annual concentration has decreased from 3.2 mg MBAS equivalent per liter in 1963 to as low as 0.3 in 1967. The mean annual concentration in the 1965-69 period has been 0.55 mg MBAS equivalent per liter in the wastewater. The mean annual concentration in the soil water at the 48-inch depth in this same period has been 0.043 mg/1 in the control area, 0.048 in the 1-inch and 0.068 in the 2-inch wastewater area. Since the control area has not received any detergent if one deducts its MBAS equivalent value from that of the wastewater treated areas the values of MBAS on the wastewater areas become even more insignificant from a water quality standpoint. The data in Tables 83 and 97 merely emphasize the diminishing importance of the surfactant component of detergents in water quality since the detergent industry changed over from branched-chain ABS to linear-chain LAS in 1965.

Since there were no comparable control suction lysimeter data for the reed canarygrass area, comparisons will be made with the 2-inch corn rotation area. Keeping in mind that the reed canarygrass area was first irrigated in 1964 as compared to 1963 for the corn rotation area, by the end of 1969 the reed canarygrass which has been irrigated year round received 486 inches of wastewater whereas the 2-inch corn rotation area with only growing season irrigation had received 360 inches of wastewater. In spite of the larger hydraulic and chemical load on the reed canarygrass area, if one looks at the water quality at the 48-inch depth in 1969 as shown in Figure 51 it is obvious that water with smaller concentrations of everything except manganese, chloride and potassium are being recharged through that area. However the only constituent which exceeds the U.S.P.H.S. drinking water recommended limits is manganese which was 0.22 mg Mn per liter or more than four times the limit of 0.05 mg Mn per liter. The value on the corn rotation area was only 0.038 mg Mn per liter. A possible explanation of the high Mn level is that the greater wetness is contributing to a higher degree of anaerobiosis and hence keeping more Mn in the more soluble divalent form. This higher degree of anaerobiosis has probably also contributed to denitrifying some of the nitrate and in helping to keep the nitrate concentration so desirably low.

The relatively high Mn levels at the 48-inch depth would not be expected to persist at greater depth as one approaches the limestone bedrock and the pH increases from values of approximately 5.2 at the 48-inch depth to values greater than 7.0. A pH difference of two units could result in a ten thousand fold decrease in solubility if based solely on solubility product relations for manganese hydroxide. It is highly probable that adsorption reactions would attenuate the manganese concentration even before the soil solution encountered zones of higher pH. Hence it is highly unlikely that undesirable amounts of manganese would reach the groundwater.

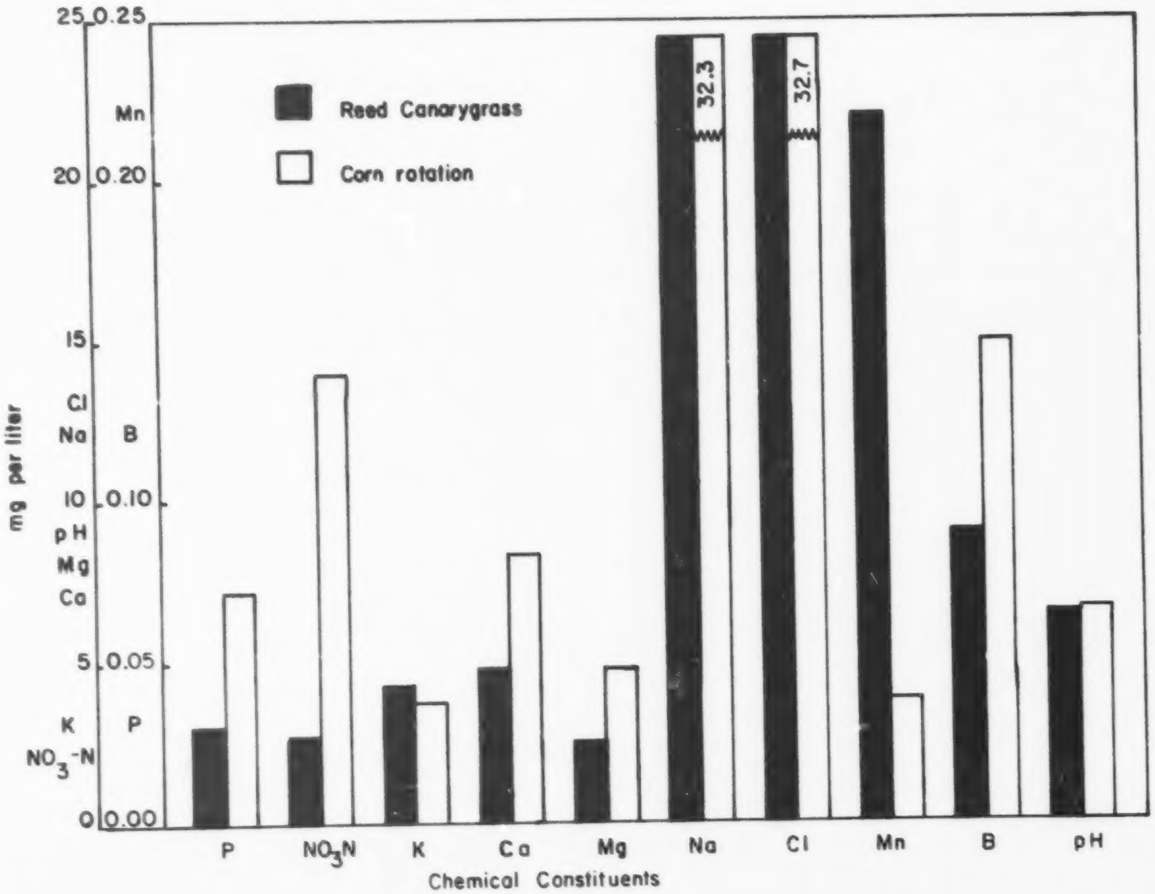

Figure 51. Mean Annual Concentration of Various Chemical Constituents in Suction Lysimeter Samples at the 48-Inch Depth in the Reed Canarygrass and Corn Rotation Areas in 1969.

Table 71. Mean Annual Concentration (mg/1) of Phosphorus in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	0.035a**[1]	0.047a	0.118b	0.044a**	0.079a	0.271b	0.046a**	0.159a	0.662b
24	0.025a**	0.021a	0.045b	0.046N.S.	0.036	0.055	0.040a**	0.039a	0.089b
48	0.032b**	0.016a	0.022ab	0.045b*	0.028a	0.036ab	0.040a**	0.030a	0.055b

Depth Inches	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	0.039a**	0.164a	0.586b	0.024a**	0.073a	0.603b
24	0.051N.S.	0.065	0.080	0.084N.S.	0.048	0.062
48	0.043N.S.	0.052	0.061	0.069N.S.	0.067	0.072

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[1] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 72. Mean Annual Concentration (mg/1) of Nitrate Nitrogen in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	6.8N.S.[1/]	4.2	4.7	4.6b**	1.7a	5.0b	1.1a**	2.4b	5.2c
24	6.1N.S.	6.7	7.7	3.3b**	1.8a	4.1b	3.1b**	2.2a	6.6c
48	5.3a**	8.2b	9.7c	4.7a**	4.9a	7.0b	3.4a**	3.8a	7.1b

Depth Inches	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	12.6N.S.	12.0	10.5	15.9N.S.	11.9	18.2
24	2.7a**	4.5b	10.6c	10.5b**	5.5a	14.2c
48	4.3a**	5.8b	9.6c	9.4b**	7.7a	14.0c

[1/] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 73. Mean Annual Concentration (mg/1) of Kjeldahl Nitrogen[1] in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	-	0.74	-	1.08	2.14	1.69	1.46	2.17	1.79
24	0.97	0.84	0.76	1.46	1.34	1.57	1.49	1.59	1.45
48	0.68	0.85	0.77	1.30	1.23	1.40	1.45	1.55	1.54

Depth Inches	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	0.98N.S.[2]	1.74	1.71	1.94N.S.	2.73	3.48
24	1.06N.S.	0.98	1.16	1.09N.S.	1.66	1.60
48	1.27N.S.	1.03	1.00	1.34N.S.	1.45	1.59

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[1] Kjeldahl nitrogen includes organic and ammonium nitrogen. Values for 1965, 1966, 1967 are low by an unknown amount because of an error in procedure and were not analyzed statistically.

[2] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 74. Mean Annual Concentration (mg/1) of Ammonium Nitrogen in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1968-1969[1/]

Depth Inches	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	2.72N.S.[2/]	0.60	0.52	0.74N.S.	1.02	1.08
24	0.36N.S.	0.48	0.45	0.68N.S.	0.77	0.61
48	0.50N.S.	0.51	0.41	0.84N.S.	0.75	0.78

[1/] Ammonium nitrogen was not determined separately from Kjeldahl nitrogen prior to 1968.

[2/] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 75. Mean Annual Concentration (mg/1) of Potassium in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1964			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	8.15N.S.[1/]	16.69	16.13	5.57N.S.	7.61	7.75	6.39N.S.	7.14	8.63
24	10.83b**	9.48b	8.18a	5.58N.S.	5.95	5.71	5.63N.S.	5.52	5.83
48	9.01N.S.	8.07	8.79	5.91ab**	5.36a	6.26b	6.04ab*	5.20a	6.25b
	1968			1969					
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2			
6	1.99N.S.	4.33	4.05	2.47N.S.	5.40	4.91			
24	0.96a*	3.03b	2.48b	2.43N.S.	3.17	3.09			
48	2.34a*	2.75a	3.95b	5.35b*	2.83a	3.73ab			

[1/] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. - not significant

Table 76. Mean Annual Concentration (mg/1) of Calcium in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	61.10N.S.[1/]	43.70	40.18	31.30N.S.	38.71	41.77	26.20a**	23.20a	32.73b
24	13.96a**	25.37c	21.73b	13.26a**	13.18a	16.40b	15.05b**	9.32a	14.90b
48	7.07a**	11.71b	11.76b	8.04a**	7.71a	9.44b	6.29ab**	5.38a	6.76b

	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	36.25b**	24.29a	21.14a	41.05N.S.	30.89	30.13
24	11.68a**	8.76a	16.01b	18.23b**	9.53a	19.43b
48	10.13b**	5.72a	6.67a	14.86b**	6.05a	8.26a

[1/] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 77. Mean Annual Concentration (mg/1) of Magnesium in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	4.15a*[1]	4.61a	5.85b	2.57N.S.	9.67	6.52	2.07a**	4.17b	5.65c
24	3.99a**	5.55b	4.70a	2.96a**	3.66b	3.48b	1.86a**	2.62b	3.13c
48	2.44a**	4.85b	7.04c	3.38a**	3.41a	5.53b	2.44a**	2.70a	4.86b

	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	1.80a**	4.00b	5.07b	1.68a**	5.11b	8.73c
24	2.26a**	2.44a	3.52b	2.76a**	2.28a	4.32b
48	3.20a**	2.80a	4.43b	3.40b**	2.65a	4.82c

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[1] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 78. Mean Annual Concentration (mg/l) of Sodium in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	2.25a**1/	35.89b	45.05c	1.29a**	37.10b	38.22b	2.01a**	34.84b	31.24b
24	2.89a**	27.17b	30.02c	2.59a**	26.80b	34.59c	1.49a**	28.74b	35.06c
48	2.03a**	19.06b	27.16c	2.85a**	20.29b	29.43c	1.57a**	23.77b	31.01c

	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	1.10a**	29.57b	26.40b	1.03a**	31.66b	35.01b
24	1.62a**	25.14b	30.12c	1.48a**	26.56b	37.64c
48	2.72a**	21.80b	28.79c	1.79a**	22.95b	32.28c

1/ The Duncan's separations are between wastewater treatments within depths and within years.
** = P(0.01), * = P(0.05), N.S. = not significant

Table 79. Mean Annual Concentration (mg/1) of Chloride in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	33.5a**[1]	40.1b	39.2a	8.8a**	49.3c	41.5b	1.4a**	21.6b	28.4c
24	10.3a**	43.2c	38.5b	10.9a**	46.7c	43.9b	7.9a**	30.7b	31.5b
48	5.6a**	25.7b	35.3c	8.8a**	31.7b	40.3c	5.2a**	28.3b	35.6c

	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	8.2a**	30.5b	31.1b	3.9a**	27.1b	31.9b
24	5.4a**	29.0b	32.0c	4.5a**	25.2b	27.6b
48	6.3a**	28.5b	34.6c	4.8a**	26.4b	32.7c

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[1] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. - not significant

Table 80. Mean Annual Concentration (mg/1) of Manganese in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	0.040N.S.[1]	0.033	-	0.036N.S.	0.035	0.030	0.041N.S.	0.035	0.041
24	0.067N.S.	0.056	0.035	0.055b**	0.058b	0.042a	0.042b**	0.049b	0.031a
48	0.100b*	0.066b	0.047a	0.072c**	0.060b	0.052a	0.053a**	0.071b	0.044a

	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	0.023N.S.	0.017	0.015	0.084N.S.	0.024	0.028
24	0.028N.S.	0.024	0.022	0.087b**	0.026a	0.030a
48	0.105c**	0.062b	0.027a	0.069b**	0.041a	0.038a

[1] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 81. Mean Annual Concentration (mg/1) of Boron in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	0.015	0.140	-	0.047a**	0.164b	0.221c	0.051a**	0.265b	0.310b
24	0.030a**[1]	0.046a	0.085b	0.039a**	0.070b	0.147c	0.034a**	0.082b	0.198c
48	0.030a**	0.041a	0.066b	0.038a**	0.058b	0.097c	0.029a**	0.065b	0.127c

	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	0.024a**	0.194b	0.253b	0.027a**	0.236b	0.242b
24	0.021a**	0.068b	0.184c	0.018a**	0.060a	0.212b
48	0.018a**	0.056b	0.116c	0.031a**	0.063b	0.151c

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[1] The Duncan's separations are between wastewater treatments within depths and within years.
** = P(0.01), * = P(0.05), N.S. = not significant

Table 82. Mean Annual pH in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	6.9a**[1]	7.6c	7.5b	6.9a**	7.4b	7.4b	7.0a**	7.4b	7.4b
24	6.6a**	6.8c	6.7b	6.5a**	6.7b	6.8b	6.4a**	6.7b	6.8c
48	6.5b**	6.4a	6.5b	6.3a**	6.4a	6.6b	6.1a**	6.2b	6.5c

Depth Inches	1968			1969			1965-1969			
	Wastewater Application - Inches Per Week									
	0	1	2	0	1	2	0	1	2	Ave.
6	6.6a**	7.0b	7.3c	6.8a**	6.9a	7.4b	6.9c[2]	7.3c	7.4c	7.2c
24	6.3a**	6.6b	6.9c	6.5a**	6.5a	6.8b	6.5b	6.7b	6.8b	6.7b
48	6.0a**	6.3b	6.6c	6.2a	6.4b	6.6c	6.3a	6.4a	6.6a	6.4a

[1] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

[2] Values in the same column not having a common letter are different at a highly significant level (P = 0.01) using Duncan's range test.

Table 83. Mean Annual Concentration (mg/1) of MBAS in Suction Lysimeter Samples at Three Depths in Corn Rotation Area Receiving Various Levels of Wastewater. 1965-1969.

Depth Inches	1965			1966			1967		
	Wastewater Application - Inches Per Week								
	0	1	2	0	1	2	0	1	2
6	0.027a**[1/]	0.048b	0.066c	0.040N.S.	0.042	0.047	0.044a**	0.081b	0.077b
24	0.008a**	0.034b	0.053c	0.016a**	0.030b	0.040c	0.043a**	0.063b	0.069b
48	0.009a**	0.026b	0.060c	0.017a**	0.023a	0.040b	0.056a*	0.063a	0.075b

Depth Inches	1968			1969		
	Wastewater Application - Inches Per Week					
	0	1	2	0	1	2
6	0.055N.S.	0.036	0.068	0.067	-	-
24	0.043N.S.	0.048	0.040	0.070N.S.	0.042	0.041
48	0.049N.S.	0.048	0.049	0.085N.S.	0.079	0.115

[1/] The Duncan's separations are between wastewater treatments within depths and within years. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 84. Mean Annual Concentration (mg/1) of Various Constituents in Suction Lysimeter Samples at Three Depths in the Reed Canarygrass Area Receiving Two Inches of Wastewater Weekly. 1966-1969.

	1966			1967			1968			1969		
Constituent	6"	24"	48"	6"	24"	48"	6"	24"	48"	6"	24"	48"
Phosphorus	0.165	0.095	0.060	0.135	0.105	0.055	0.220	0.105	0.060	0.205	0.195	0.030
MBAS	0.025	0.025	0.015	0.045	0.055	0.055	0.145	0.050	0.050	0.060	0.063	0.063
Nitrate-N	0.8	2.3	3.9	0.5	1.3	3.3	0.5	1.5	3.2	0.6	1.0	2.7
Organic and Ammoniacal-N	†	1.4	1.4	2.2	1.8	1.5	2.8	1.4	1.2	3.0	3.5	2.4
Chloride	39.4	40.2	24.8	31.0	34.6	27.6	24.4	33.6	31.5	36.6	40.0	38.3
Potassium	6.0	6.5	6.2	7.2	6.2	7.1	5.4	3.0	3.3	8.4	5.9	4.2
Calcium	7.7	15.9	7.3	16.4	14.0	6.1	24.5	11.4	5.4	32.4	12.2	4.8
Magnesium	2.9	5.2	3.6	4.2	3.6	2.8	4.8	2.9	3.0	6.4	3.4	2.6
Manganese	0.27	0.61	0.68	0.27	0.29	0.34	0.05	0.26	0.25	0.44	0.19	0.22
Boron	0.06	0.09	0.06	0.23	0.17	0.08	0.29	0.19	0.07	0.34	0.23	0.09
Sodium	17.2	26.7	16.3	32.1	30.2	22.2	37.5	28.7	22.2	31.3	30.9	24.4
pH	7.4	6.7	6.5	7.3	6.8	6.5	7.3	6.9	6.6	7.4	6.8	6.5

† Not Determined

Table 85. The Effect of Years on Mean Annual Concentration (mg/1) of Phosphorus in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	0.035	0.044	0.046	0.039	0.024	N.S.[1]
24	0.025a	0.046a	0.040a	0.051ab	0.084b	*
48	0.032a	0.045a	0.040a	0.043a	0.069b	*
			1 inch/week			
6	0.047a	0.079a	0.159b	0.164b	0.073a	**
24	0.021a	0.036b	0.039b	0.065c	0.048bc	**
48	0.016a	0.028b	0.030b	0.052c	0.067d	**
			2 inches/week			
6	0.118a	0.271b	0.662c	0.586c	0.603c	**
24	0.045a	0.055a	0.089c	0.080bc	0.062ab	**
48	0.022a	0.036b	0.055c	0.061c	0.072c	**

[1] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. not significant

Table 86. The Effect of Years on Mean Annual Concentration (mg/1) of Nitrate Nitrogen in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	6.8b	4.6b	1.1a	12.6c	15.9c	**[1]
24	6.1b	3.3a	3.1a	2.7a	10.5c	**
48	5.3b	4.7b	3.4a	4.3ab	9.3c	**
			1 inch/week			
6	4.2b	1.7a	2.4a	12.0c	11.9c	**
24	6.7c	1.8a	2.2a	4.6b	5.5bc	**
48	8.2d	4.9b	3.8a	5.8c	7.7d	**
			2 inches/week			
6	4.7a	5.0a	5.2a	10.5b	18.2c	**
24	7.7b	4.1a	6.6b	10.7c	14.2d	**
48	9.7b	7.0a	7.1a	9.6b	14.0c	**

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[1] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 87. The Effect of Years on Mean Annual Concentration (mg/l) of Kjeldahl Nitrogen in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.[1]

Depth Inches	1965	1966	1967	1968	1969
			0 inch/week		
6	-	1.08	1.46	0.98	1.94
24	0.97	1.46	1.49	1.06	1.09
48	0.68	1.30	1.45	1.27	1.34
			1 inch/week		
6	0.74	2.14	2.17	1.74	2.73
24	0.84	1.34	1.59	0.98	1.66
48	0.85	1.23	1.55	1.03	1.45
			2 inches/week		
6	0.30	1.69	1.79	1.71	3.48
24	0.76	1.57	1.45	1.16	1.60
48	0.77	1.40	1.54	1.00	1.59

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[1] Error in procedure resulted in losses of unknown amounts of ammonium nitrogen in 1965, 1966 and 1967 therefore statistical treatment was not attempted.

Table 88. The Effect of Years of Mean Annual Concentration (mg/l) of Ammonium Nitrogen in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1968-1969.[1]

Depth Inches	1968	1969
	0 inch/week	
6	2.72	0.74
24	0.36	0.68
48	0.50	0.84
	1 inch/week	
6	0.60	1.02
24	0.48	0.77
48	0.51	0.75
	2 inches/week	
6	0.52	1.08
24	0.45	0.61
48	0.41	0.78

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[1] Separate determination of ammonium nitrogen was not made prior to 1968. Test for significance not attempted.

Table 89. The Effect of Years on Mean Annual Concentration (mg/l) of Potassium in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	8.15b	5.57ab	6.39b	1.99a	2.47a	**[1]
24	10.83c	5.58b	5.63b	0.96a	2.43a	**
48	9.01c	5.91b	6.04b	2.34a	5.35b	**
			1 inch/week			
6	16.69b	7.61a	7.14a	4.33a	5.40a	**
24	9.48c	5.95b	5.52b	3.03a	3.17a	**
48	8.07c	5.36b	5.20b	2.75a	2.83a	**
			2 inches/week			
6	16.13c	7.75ab	8.63b	4.05a	4.91a	**
24	8.18c	5.71b	5.83b	2.48a	3.09a	**
48	8.79c	6.26b	6.25b	3.95a	3.73a	**

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[1] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 90. The Effect of Years on Mean Annual Concentration (mg/1) of Calcium in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	61.10C	31.30ab	26.20a	36.25ab	41.05b	**[1]
24	13.96	13.26	15.05	11.68	18.23	N.S.
48	7.07ab	8.04ab	6.29a	10.13b	14.86c	**
			1 inch/week			
6	43.70b	38.71b	23.20a	24.29a	30.89ab	**
24	25.37b	13.18a	9.32a	8.76a	9.53a	**
48	11.71c	7.71b	5.38a	5.72a	6.05ab	**
			2 inches/week			
6	40.18b	41.77b	32.73b	21.14a	30.13b	**
24	21.73b	16.40a	14.90a	16.01a	19.43b	**
48	11.76c	9.44b	6.76a	6.67a	8.26ab	**

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[1] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 91. The Effect of Years on Mean Annual Concentration (mg/1) of Magnesium in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	4.15b	2.57a	2.07a	1.80a	1.68a	**[1]
24	3.99c	2.96b	1.86a	2.26ab	2.76b	**
48	2.44a	3.38b	2.44a	3.20ab	3.40b	**
			1 inch/week			
6	4.61	9.67	4.17	4.00	5.11	N.S.
24	5.55c	3.66b	2.62a	2.44a	2.28a	**
48	4.85c	3.41b	2.70a	2.80a	2.65a	**
			2 inches/week			
6	5.85a	6.52a	5.65a	5.07a	8.73b	**
24	4.70b	3.48a	3.13a	3.52a	4.32b	**
48	7.04c	5.53b	4.86ab	4.43a	4.82ab	**

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[1] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 92. The Effect of Years on Mean Annual Concentration (mg/1) of Sodium in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	2.25	1.29	2.01	1.10	1.03	N.S.[1/]
24	2.89	2.59	1.49	1.62	1.48	N.S.
48	2.03abc	2.85c	1.57a	2.72bc	1.79ab	**
			1 inch/week			
6	35.89	37.10	34.84	29.57	31.66	N.S.
24	27.17ab	26.80ab	28.74b	25.14a	26.56ab	*
48	19.06a	20.29b	23.77d	21.80c	22.95cd	**
			2 inches/week			
6	45.05d	38.22cd	31.24b	26.40a	35.01bc	**
24	30.02a	34.59b	35.06bc	30.12a	37.64c	**
48	27.16a	29.43b	31.01bc	28.79ab	32.28c	**

[1/] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 93. The Effect of Years on Mean Annual Concentration (mg/1) of Chloride in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 Inch/week			
6	33.5c	8.8b	1.4a	8.2b	3.9ab	**[1]
24	10.3c	10.9c	7.9b	5.4a	4.5a	**
48	5.6a	8.8b	5.2a	6.3a	4.8a	**
			1 inch/week			
6	40.1b	49.3b	21.6a	30.5a	27.1a	**
24	43.2d	46.7c	30.7b	29.0ab	25.2a	**
48	25.7a	31.7c	28.3b	28.5b	26.4a	**
			2 inches/week			
6	39.2b	41.5b	28.4a	31.1a	31.9a	**
24	38.5c	43.9d	31.5b	32.0b	27.6a	**
48	35.3b	40.3c	35.6b	34.6b	32.7a	**

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[1] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 94. The Effect of Years on Mean Annual Concentration (mg/l) of Manganese in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	0.047	0.041	0.036	0.023	0.084	N.S.[1]
24	0.067bc	0.055b	0.042ab	0.028a	0.087c	**
48	0.100bc	0.072b	0.053a	0.105c	0.069ab	**
			1 inch/week			
6	0.033	0.035	0.035	0.017	0.024	N.S.
24	0.056bc	0.058c	0.049b	0.024a	0.026a	**
48	0.066	0.060	0.071	0.062	0.041	N.S.
			2 inches/week			
6	-	0.030ab	0.041b	0.015a	0.028ab	**
24	0.035bc	0.042c	0.031b	0.022a	0.030ab	**
48	0.047bc	0.052c	0.044b	0.027a	0.038ab	**

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[1] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 95. The Effect of Years on Mean Annual Concentration (mg/l) of Boron in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	0.015a	0.047ab	0.051b	0.024a	0.027a	**[1]
24	0.030ab	0.039b	0.034b	0.021a	0.018a	**
48	0.030b	0.038c	0.029b	0.018a	0.031bc	**
			1 inch/week			
6	0.140	0.164	0.265	0.194	0.236	N.S.
24	0.046a	0.070bc	0.082c	0.068abc	0.060ab	**
48	0.041	0.058	0.065	0.056	0.063	N.S.
			2 inches/week			
6	-	0.221a	0.310b	0.253a	0.242a	*
24	0.085a	0.147b	0.198c	0.184c	0.212c	**
48	0.066a	0.097b	0.127c	0.116c	0.151d	**

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[1] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 96. The Effect of Years on Mean Annual pH in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level. 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
0 inch/week						
6	6.9bc	6.9bc	7.0c	6.6a	6.8ab	**[1/]
24	6.6c	6.5bc	6.4b	6.3a	6.5bc	*
48	6.5c	6.3b	6.1a	6.0a	6.2b	**
1 inch/week						
6	7.6c	7.4b	7.4b	7.0a	6.9a	**
24	6.8c	6.6b	6.7b	6.6b	6.5a	**
48	6.4b	6.4b	6.2a	6.3b	6.4b	**
2 inches/week						
6	7.5b	7.4ab	7.4ab	7.3a	7.4ab	*
24	6.7a	6.8b	6.9b	6.9b	6.8b	**
48	6.5a	6.6b	6.5a	6.6b	6.6b	**

[1/] The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Table 97. **The Effect of Years on Mean Annual Concentration (mg/1) of MBAS in Suction Lysimeter Samples at Three Depths in the Corn Rotation Area Segregated by Wastewater Treatment Level.** 1965-1969.

Depth Inches	1965	1966	1967	1968	1969	
			0 inch/week			
6	0.027	0.040	0.044	0.055	0.067	N.S.1/
24	0.008a	0.016a	0.043b	0.043b	0.070b	**
48	0.009a	0.017a	0.056b	0.049b	0.085b	**
			1 inch/week			
6	0.048a	0.042a	0.081b	0.036a	-	**
24	0.034a	0.030a	0.063b	0.048b	0.042ab	**
48	0.026a	0.023a	0.063c	0.048b	0.079c	**
			2 inches/week			
6	0.066c	0.047b	0.077c	0.068c	0.032a	**
24	0.053b	0.040a	0.069b	0.040a	0.041ab	**
48	0.060b	0.040a	0.075c	0.049ab	0.115d	**

1/ The Duncan's separations are between years within depths and within wastewater treatments. ** = P(0.01), * = P(0.05), N.S. = not significant

Soil Chemical Characteristics

Previous Work. The physical and chemical changes that occur in soil through which wastewater percolates have been given less attention than the changes occurring in the effluent itself. However, particularly in the Western States, much work has been done in attempts to classify irrigation waters on the bases of relative as well as total ionic concentration. Scofield and Headley (49) found that a predominance of sodium in irrigation water caused a decrease in aggregation of the soil and a reduction in the rate of infiltration of water. Where calcium was the major cation just the opposite was found to be true. They concluded that for water to be acceptable for irrigation, the ratio of sodium to calcium plus magnesium should not exceed 1:1.

Kelly et al. (50) investigated the effects of relative ionic composition and total concentration of ions in solution on the suite of ions borne by the exchange complex of the soil. They found that the adsorption of sodium by the soil from a sodium-calcium solution increased with an increase in the ratio of sodium to calcium and with an increase in the total ionic concentration. Above a sodium:calcium ratio of 2:1, sodium was adsorbed in significant amounts by the soil. However, the adsorption of sodium was influenced by the kind of base held by the soil and was lower when calcium was present on the exchange complex than when magnesium was present. The results were attributed to the differential replacing power of these bases as previously measured (51). It was also found that the adsorption of sodium by the soil from a sodium-calcium solution was due largely to the replacement of magnesium. On the other hand, tests with solutions containing various ratios of sodium to calcium plus magnesium showed that the sodium was adsorbed by the soil mainly at the expense of calcium. Evidence cited by the authors indicated that because of evapotranspiration, the concentration of the soil solution could undergo a six-fold increase compared to the concentration of the irrigation water. In such a situation, the removal of calcium from solution either by precipitation or by root uptake could result in an unfavorable relative concentration of sodium and, consequently, adsorption of sodium by the soil. The authors, therefore, have recommended that the ratio of sodium to calcium plus magnesium in irrigation water should not exceed 1:1 unless the total salt concentration of the water was quite low.

Wilcox (52) classified irrigation water on the bases of percentage sodium and total cations present. The percentage sodium was determined according to the following equation

$$\text{Percentage Na} = \frac{\text{Na}}{\text{Ca} + \text{Mg} + \text{K} + \text{Na}} \times 100 ,$$

where the concentrations of cations are expressed in me/ℓ. He regarded the water as acceptable for irrigation of agricultural lands only if the percentage sodium was less than 80 and if the total concentration of cations did not exceed 25 me/ℓ.

In 1953, the United States Regional Salinity Laboratory (53) proposed a classification of irrigation water based on the sodium adsorption ratio (SAR) and the total salt concentration as measured by electrical conductivity.

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}}$$

where concentrations of the cations are expressed in me/ℓ

The sodium adsorption ratio was believed to be theoretically more closely related to the exchangeable sodium percentage (ESP) in the soil than were the simpler sodium percentage values. Thus, irrigation water may be considered to be of low sodium hazard if the SAR was not greater than ten. However, in order to maintain this classification, the maximum permissible SAR would decrease as the total salt concentration increased.

Based on the above classifications, the quality of wastewater applied to cropland, while not excellent in every respect, has usually not had any deleterious effects on the soil. Henry et al. (24) reported that in soil that had been treated with sewage effluent containing 680 ppm of sodium the concentration of exchangeable sodium amounted to 2.37 m.e./100 grams. They also found that owing to the preponderance of sodium in the effluent, calcium and magnesium in the soil were significantly diminished. The exchangeable potassium was not affected by percolation of the effluent although there was twice as much potassium added as there was removed by the reed canarygrass being grown. They concluded that the potassium was being fixed in a nonexchangeable form. It is noteworthy that the authors reported no difficulty with percolation during their three-year study.

In an investigation of the spreading of primary sewage effluent on California soils (37) it was reported that calcium and magnesium in the soil both decreased while sodium, potassium and ammonium increased. It was also noted that although the ratio of monovalent cations to the total cations in the effluent was 0.641, permeability of the soil was not affected probably because of the low clay content (3-10 percent). In general the surface soil showed the greatest exchange between monovalent and divalent ions but there was no significant correlation with depth.

In Israel, Heukelekian (25) reported that plots irrigated at rates of 20-30 inches per year with sewage effluent showed an accumulation of salts, especially chlorides, and these were concentrated in the upper layers of the soil. During the rainy season, the salts were removed by leaching and the soil returned to its pre-irrigation levels with respect to salt content. Gradual increases in organic matter were also observed in the surface layers of the irrigated plots.

The general preoccupation with exchangeable sodium stems from the well documented research in irrigation agriculture which has shown that when the exchangeable sodium percentage reaches a value of 10 to 15 a deterioration of soil structure and adverse effects on infiltration can be expected in medium and fine textured soils.

Exchangeable Cations. Soil samples were taken by one-foot intervals at 21 locations in each wastewater treatment area in 1963, 1965, 1966, 1967, 1968 and 1969 in the corn rotation area. In the reed canarygrass area sampling at the same depth intervals was done at 18 locations in 1969. In the Gamelands hardwood forest area samples were taken in 1967 from nine locations in the wastewater area and from three locations in the control area.

The exchangeable bases were extracted with normal ammonium acetate at pH 7.0; the exchangeable hydrogen with barium chloride-triethanolamine at pH 8. Details of the soil analytical procedures are given in the Appendix. The exchangeable cation data and other chemical data are given in Tables 98 to 105 on pages 205 to 212.

Summarized over the five soil depths and six years, Figure 52 indicates that in the corn rotation area there was a significant change due to wastewater treatment only in the case of exchangeable magnesium and sodium. Figure 53 indicates that the relative increase in exchangeable magnesium due to wastewater application was greatest in the upper foot. Below the second foot increases were greater with the 1-inch per week application than with the 2-inch per week treatment. In the third and fifth foot the 2-inch treatment was significantly different from the control (0-inch) only at the 5% level of probability. In the fourth foot the 2-inch treatment value was not significantly greater than the control.

Figure 54 indicates that exchangeable sodium increases were also greatest in the upper foot and it appears that both the one and two inch per week treatments have peaked at a value of approximately 0.5 m.e./100 grams of soil, equivalent to an ESP value of approximately 2.5 to 3.0%. Thus it appears highly probable that with the present wastewater quality, with an SAR value less than 2.0, one need not be concerned about a sodium hazard to soil structure and permeability.

With respect to the other principal exchangeable cations, K, Ca and H, there were no significant treatment effects when averaged over depths and years (Figure 52) or within depths over years. Since the area had been limed during the previous farm management program, a sharp decrease of Ca with depth was present originally and this depth effect has persisted.

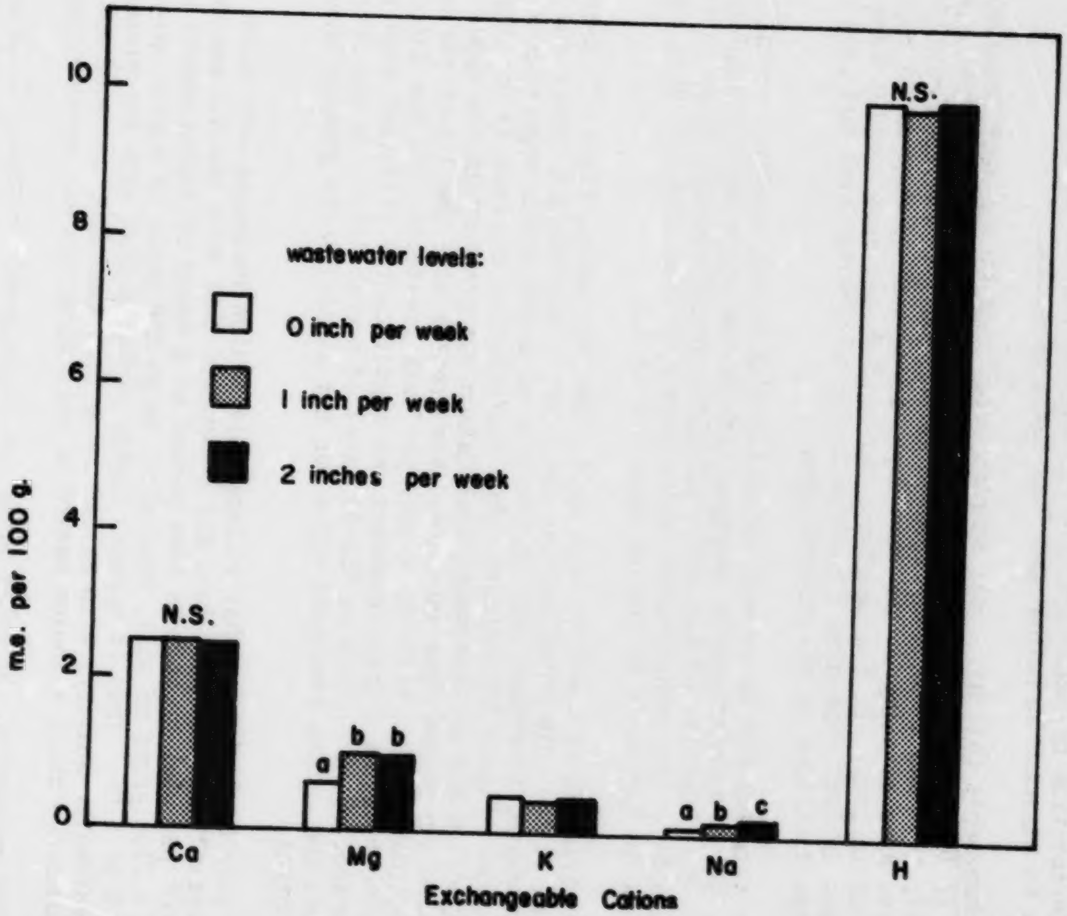

Figure 52. Effect of Various Wastewater Levels on the Corn Rotation Area on Exchangeable Cations Averaged Over Five One-Foot Depth Intervals and Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter for Any Constituent Are Not Significantly Different. P = 0.01

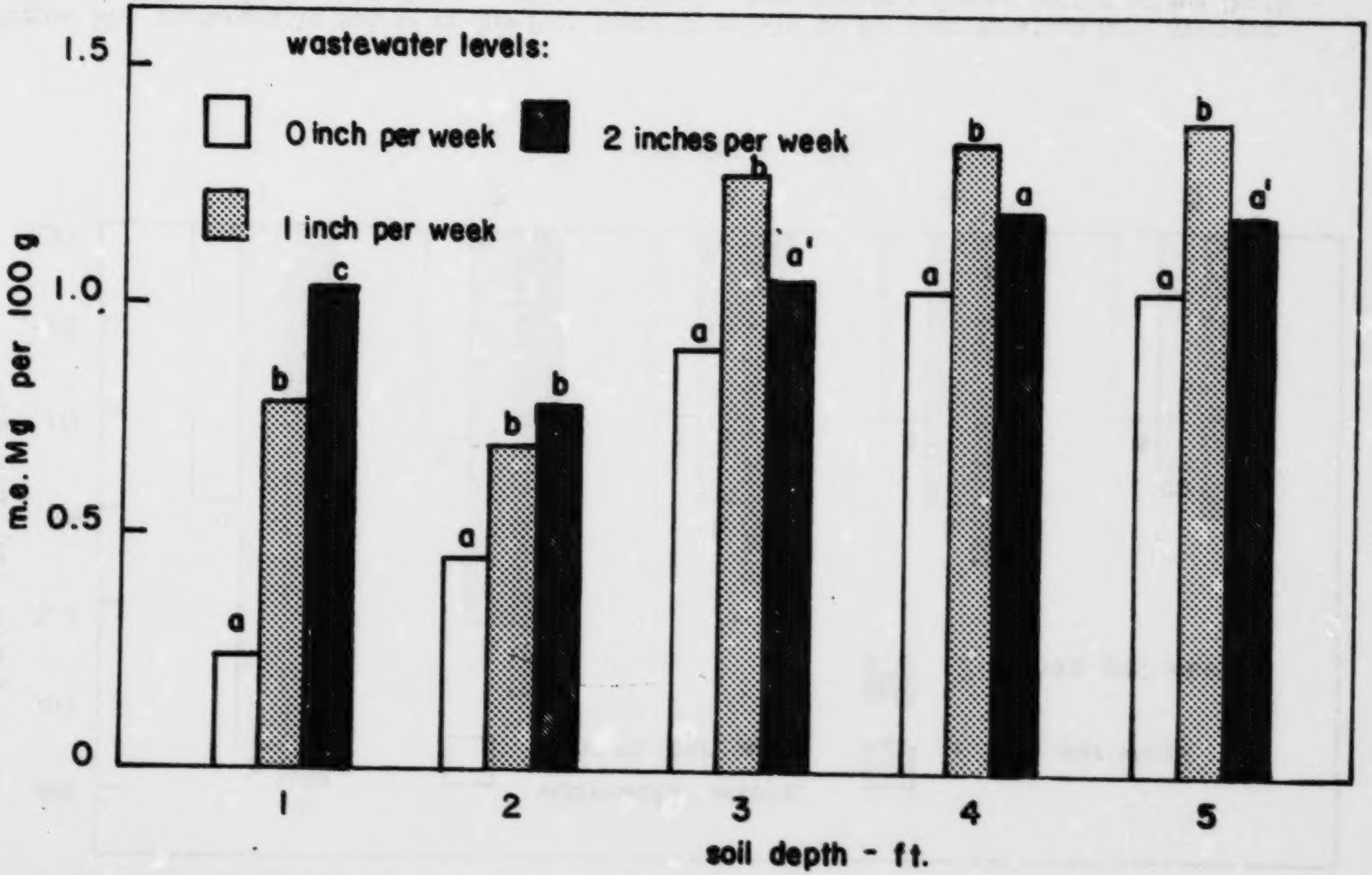

Figure 53. Exchangeable Magnesium at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01

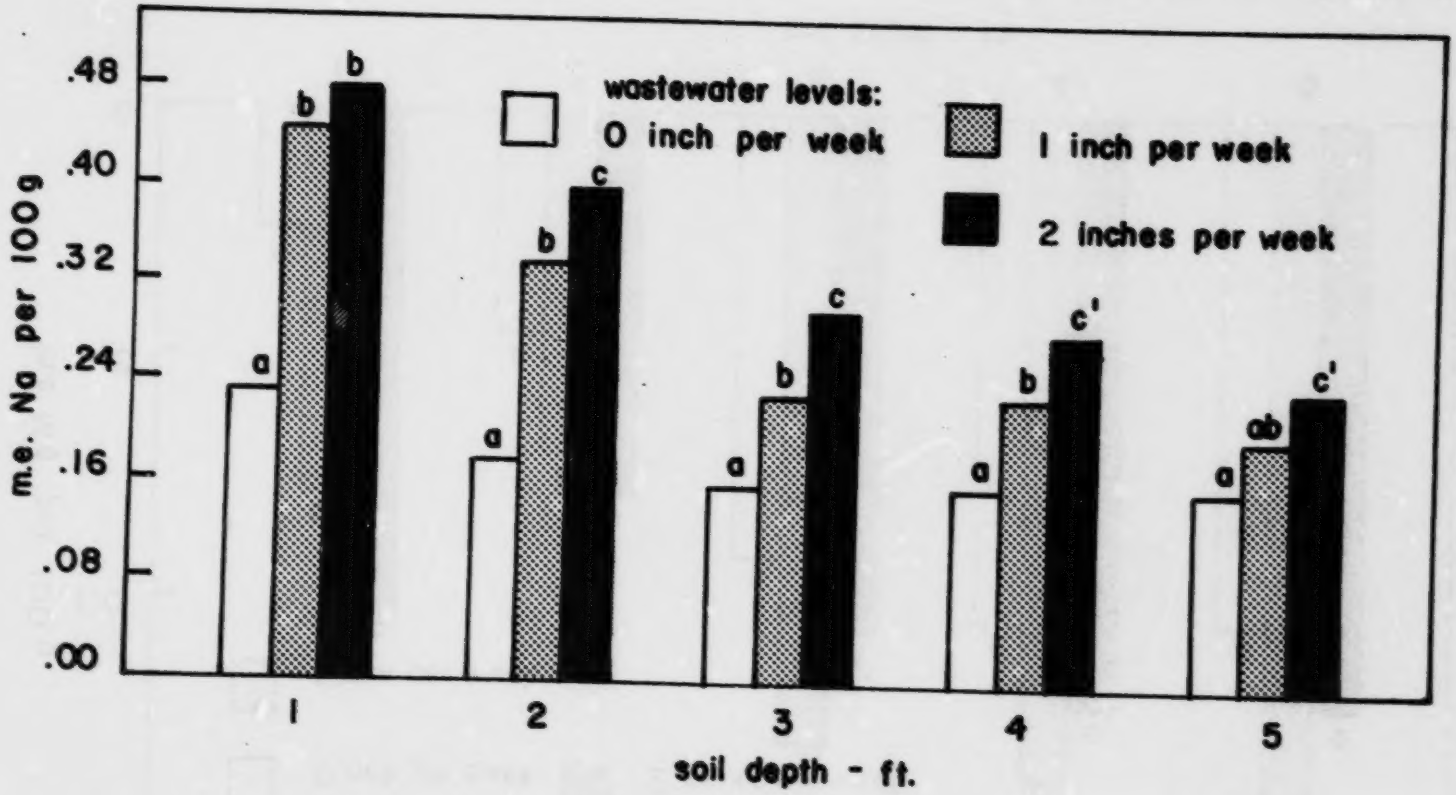

Figure 54. Exchangeable Sodium at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01

The small increases in exchangeable Mg and Na were reflected in an increase in base saturation which in turn was reflected in a significant increase in pH in the upper two feet of soil for both the 1-inch and 2-inch treatments (Figure 55).

Although manganese (Mn) is not commonly measured among the exchangeable cations because it is usually present only in small amounts, it was included in this study because of the possible effect of the increased wetness in increasing the solubility of Mn by oxidation-reduction reactions. The data in Figure 56 indicate that differences due to wastewater treatments were not significant in the more aerobic and less acid upper two feet of soil but were highly significant ($P = 0.01$) for the one-inch treatment and significant ($P = 0.05$) for the 2-inch treatment in the lower three feet. Klausner (54) in aeration studies in the corn rotation area found a slightly lower mean oxygen diffusion rate in the 1-inch and 2-inch treatment areas. As a consequence of diminished availability of oxygen, the higher oxides of manganese, which are visible in the soil as black coatings on structural peds, could be reduced to divalent manganese and thereby become more soluble and interact with the exchange sites.

In the reed canarygrass area (Table 104) the larger hydraulic loads have resulted in an even greater quantity of exchangeable manganese in the second and third foot, 12.6 and 9.49 micrograms Mn per gram of soil compared to 3.97 and 6.75 micrograms in 1969 in the 2nd and 3rd foot of the two-inch corn rotation area. The lower oxidation status and hence greater possibility for denitrification in the reed canarygrass area may be responsible in part for the substantially lower nitrate levels in that area.

Soil Chloride. Since the Hublersburg soil is known to contain substantial amounts of free iron oxides (55, 56) and such oxides have a substantial capacity for adsorbing anions, soil samples were extracted with $0.05N \cdot NH_4 NO_3$ to determine the adsorbed chloride content. The data in Table 106 and Figure 57 show that adsorbed chloride increased with soil depth and that the differences between the wastewater treatments were not significant in the first foot where free iron oxide was generally found to be less than 4%. However in the deeper layers where free iron oxide ranged from 5 to 6%, adsorbed chloride in the 2-inch treatment was highly significantly greater and in the 1-inch treatment significantly greater than in the control for the second and third foot. In the fourth and fifth foot differences in adsorbed chloride were highly significant for all three wastewater treatments.

In the reed canarygrass area (Table 104) the adsorbed chloride was uniformly high throughout the five foot depth but lower than the maximum concentrations occurring in the corn rotation area. This may reflect the wash-out equilibrium concentration of the larger hydraulic loading on this area whereas, on the corn rotation area with a small

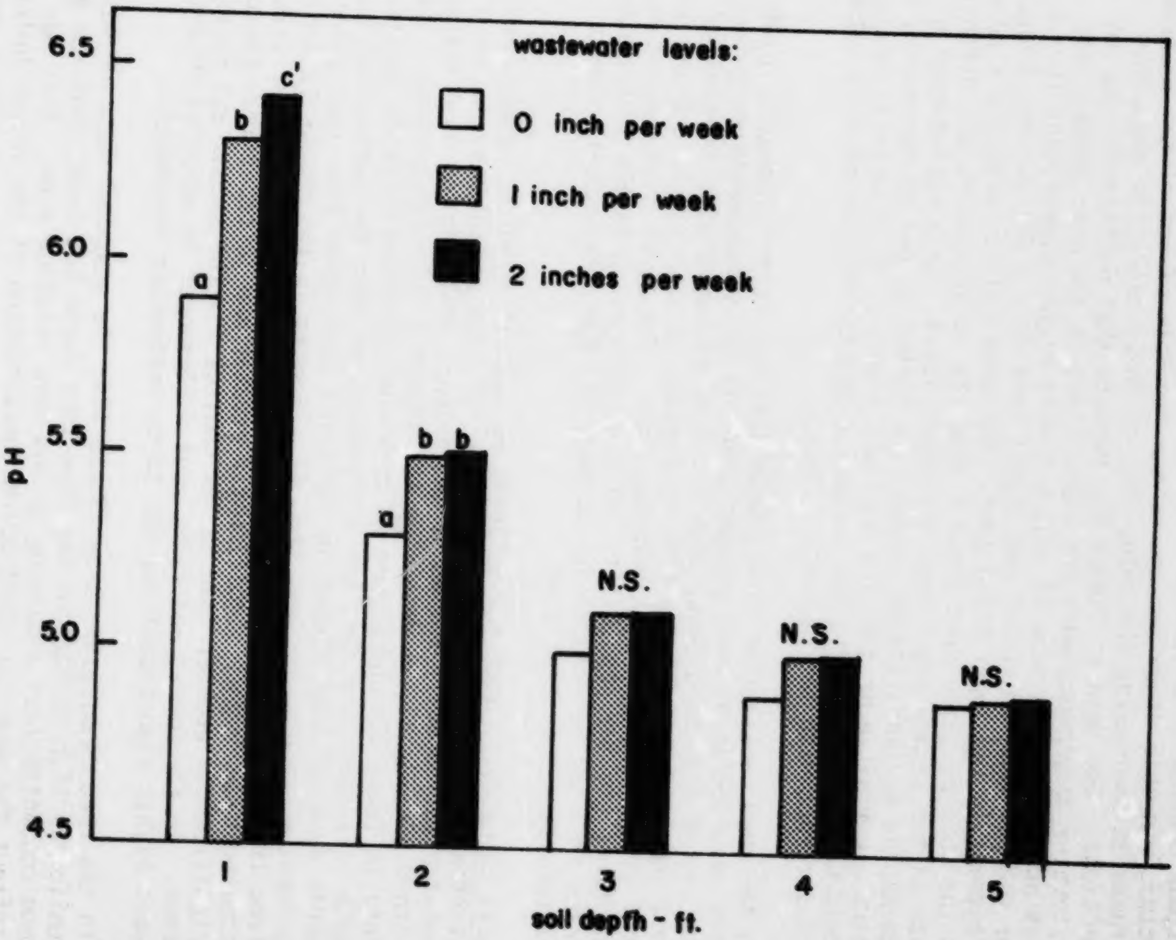

Figure 55. Soil pH at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01

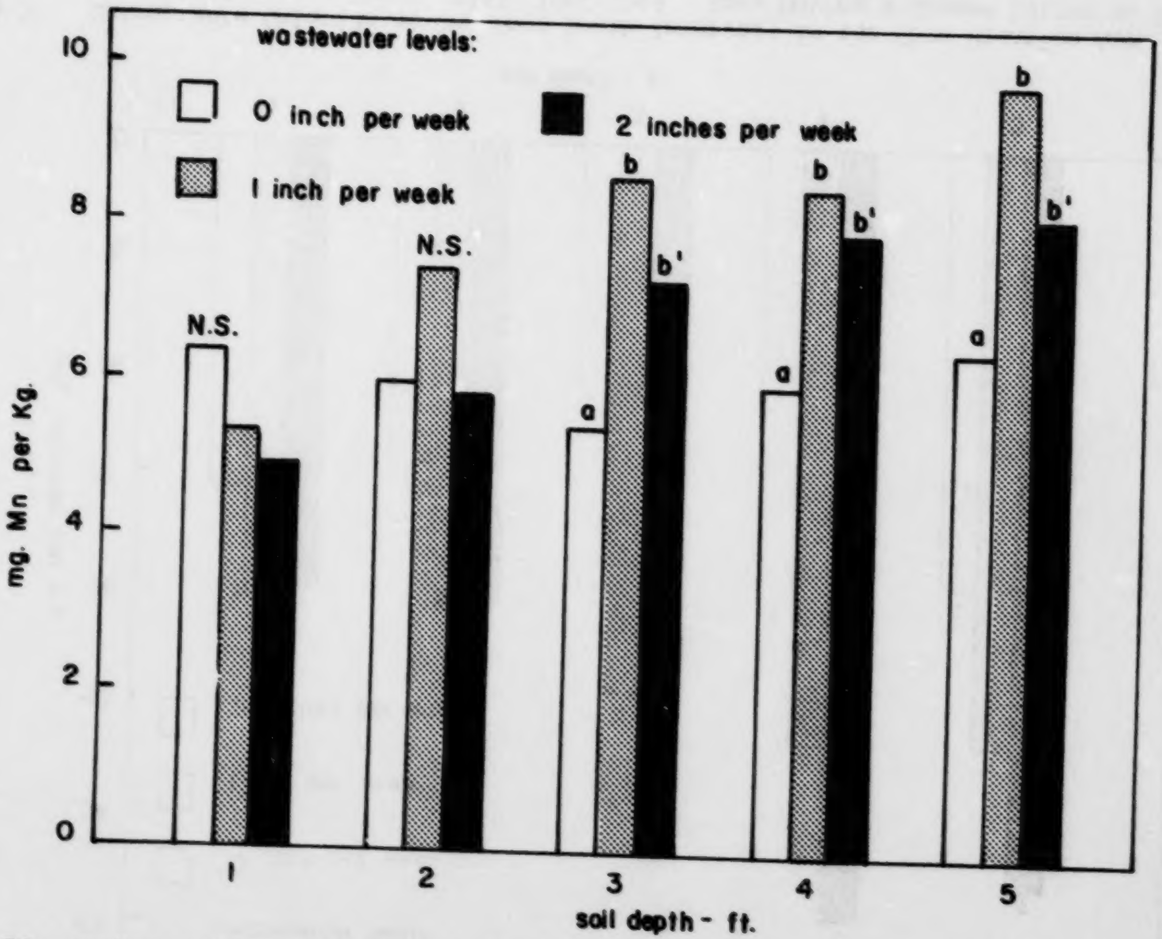

Figure 56. Exchangeable Manganese at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01

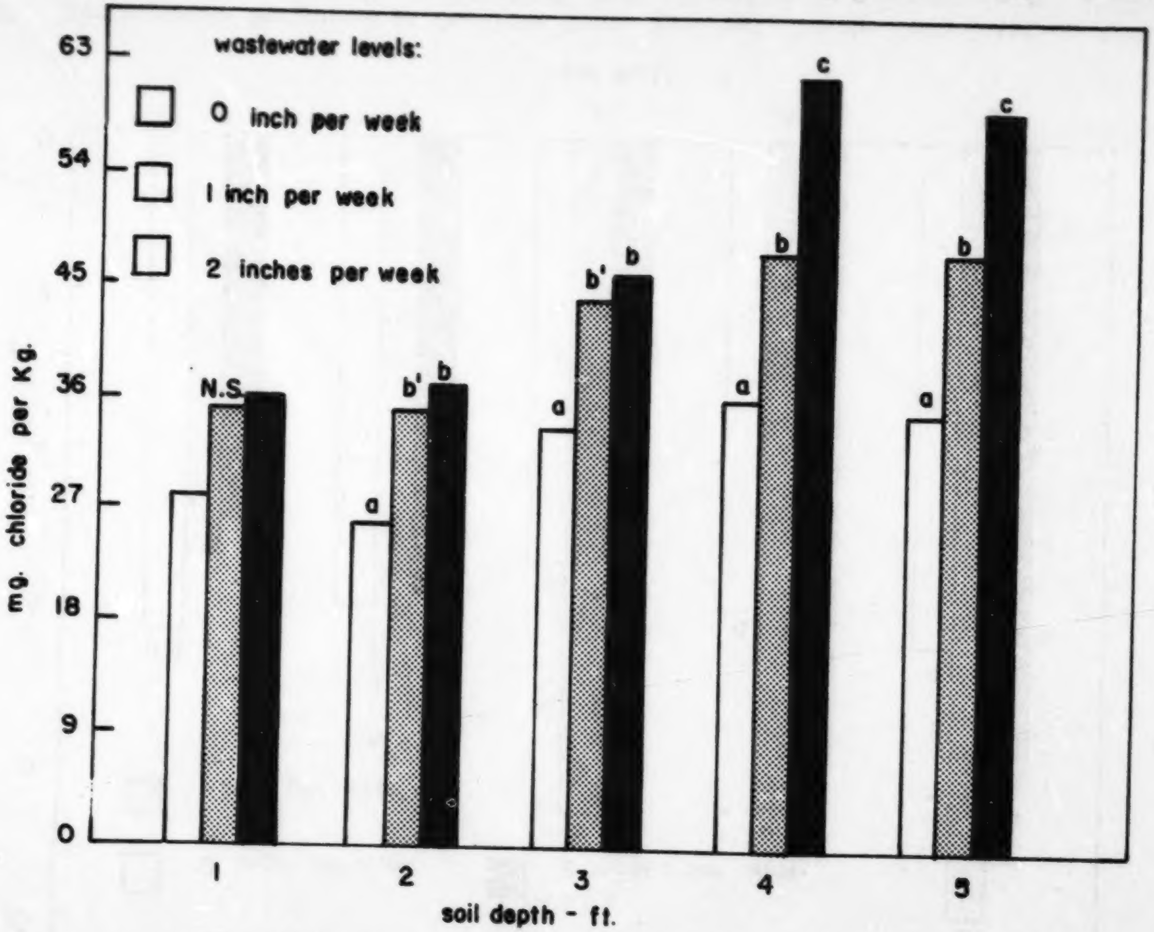

Figure 57. Extractable Chloride at One-Foot Depth Intervals in the Corn Rotation Area Averaged Over Six Sampling Years, 1963, 1965-1969. Bars Having a Common Letter at Any Depth Are Not Significantly Different. P = 0.01

hydraulic load combined with evaporational loss of water, the detention time of chloride in the upper five feet would be longer and the equilibrium concentration greater and hence the adsorbed chloride content should be greater.

Assuming a conservative 4,000,000 pounds per acre foot of soil in the corn rotation area, the total adsorbed chloride in the 2-inch treatment area for the five-foot depth was 1216 pounds per acre in 1969, approximately 3.8 times as much as was added in the 32 inches of wastewater applied that year. In contrast to this the Morrison sandy loam at the Gamelands area which contains less than half as much free iron oxide and had been treated with 208 inches of wastewater in two years prior to sampling in 1967 had only 712 pounds of adsorbed chloride per acre (Table 105). As with the reed canarygrass area the larger hydraulic load on the sandy Gamelands area soil probably resulted in an adsorbed chloride content which represents a wash-out equilibrium concentration with an even shorter detention time in the upper five feet than in the reed canarygrass area.

The years effect on adsorbed chloride in the corn rotation area was not consistent with time although there appeared to be a plateau in content in the period 1966-1968. These three years each had above normal precipitation for the three months, Sept, Oct, and Nov just prior to when the soil samples were obtained in November. In 1969 precipitation was slightly below normal for these three months and almost four inches below normal for the year. As a consequence adsorbed chloride was substantially higher than in 1968. Because of the weak bonding forces between chloride and soils, adsorbed chloride could be expected to decrease by desorption during leaching by precipitation if application of chlorides ceased or diminished.

Soil Boron. The ammonium acetate extract for exchangeable bases was also analyzed for boron on the emission spectrograph and it was found that although the extracted boron in the corn rotation area was slightly greater in the wastewater treated plots than in the control plots the differences were not statistically significant (Table 107). The low concentrations in the applied wastewater (0.4mg B per liter) would not be expected to result in a large adsorbed boron level in the soil even though free iron and aluminum hydrated oxides have been shown to be capable of adsorbing relatively large amounts of boron (57). The boron relations will be described in greater detail in a later section summarizing the work of Jardine (55).

Soil Nitrogen and Organic Matter. Neither nitrogen nor organic matter levels were significantly different as a result of the wastewater treatments on the corn rotation area (Table 108). The highly significant depth difference for both nitrogen and organic matter resides in the large difference between the values in the first foot and the other four feet. Between the second foot and the lower three feet the nitrogen values were highly significantly different (P = 0.01) but with the organic matter values the differences were only significantly different (P = 0.05). In 1968 the five foot depth of soil contained 8120, 7840 and 7760 pounds of nitrogen per acre, respectively in the 0, 1 and 2-inch wastewater treatment areas, over half of which is located in the upper foot of soil. The same treatments contained, respectively, 92.8, 74.0 and 79.7 tons of organic matter to a depth of five feet, approximately 70% of which is located in the upper foot of soil. The annual nitrogen and organic matter loads from the wastewater applied to the corn rotation have been relatively small, averaging about 160 pounds of nitrogen and approximately 500 pounds of organic matter per acre per year for the 2-inch per week treatment, with an average of 50 inches of wastewater being applied annually. With cognizance of the nitrogen removals in the crops and leaching losses of nitrate and the small amount of organic matter added in the effluent it is understandable why one should not expect to find large changes in total nitrogen or organic matter.

Table 98. Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1963

Depth inches	Wastewater Level inches/week	Exchangeable Cations							pH	Mn3/
		K^+	Ca^{2+}	Mg^{2+}	Na^+	H^+	E.S.P.1/	B.S.2/		
			M.E./100g				%	%		µg/g
0-12	0	0.81	4.95	0.27	0.09	6.69	0.8	47.0	6.0	14.62
	1	0.63	5.44	0.34	0.26	6.29	2.1	51.5	6.4	14.92
	2	0.63	4.81	0.43	0.26	6.24	2.1	49.6	6.2	13.77
12-24	0	0.51	2.83	0.46	0.09	7.79	0.8	33.3	5.1	17.97
	1	0.45	3.05	0.70	0.12	6.46	1.1	40.1	5.4	23.56
	2	0.53	3.24	1.01	0.19	7.23	1.6	40.6	5.2	14.12
24-36	0	0.67	1.71	0.85	0.09	10.29	0.7	24.6	4.9	8.48
	1	0.42	2.36	1.83	0.09	9.40	0.6	33.4	5.0	23.32
	2	0.44	1.49	1.42	0.10	10.20	0.7	25.3	4.9	15.40
36-48	0	0.65	1.74	1.01	0.10	10.41	0.7	27.7	4.8	12.68
	1	0.47	1.58	1.61	0.10	8.74	0.8	30.1	4.9	22.43
	2	0.61	0.97	1.12	0.14	8.57	1.2	24.9	4.8	18.16
48-60	0	0.67	0.99	0.88	0.09	8.48	0.8	24.8	4.9	18.37
	1	0.57	1.22	1.45	0.09	8.12	0.8	28.8	4.9	24.41
	2	0.60	0.84	1.30	0.09	9.37	0.7	23.3	5.0	17.82

1/ Exchangeable sodium percentage.

2/ Base saturation.

3/ Extracted with exchangeable bases.

Table 99. Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1965

Depth inches	Wastewater Level inches/week	Exchangeable Cations K^+	Ca^{2+}	Mg^{2+} M.E./100g	Na^+	H^+	E.S.P.[1/] %	B.S.[2/] %	pH	Mn[3/] µg/g
0-12	0	0.58	4.74	0.23	0.51	6.55	4.0	48.1	6.0	4.05
	1	0.47	4.27	0.51	0.66	6.34	5.4	48.2	6.2	3.04
	2	0.50	5.06	0.76	0.66	6.24	4.9	53.5	6.4	2.78
12-24	0	0.42	2.62	0.46	0.16	7.19	1.5	34.6	5.1	6.04
	1	0.43	2.45	0.76	0.36	8.60	2.9	31.7	5.1	6.59
	2	0.38	3.42	0.84	0.56	8.69	4.0	37.4	5.4	5.70
24-36	0	0.47	1.76	1.20	0.15	8.96	1.2	28.6	5.0	8.39
	1	0.47	1.19	1.17	0.21	9.15	1.7	24.9	4.9	8.44
	2	0.47	1.56	1.01	0.26	8.92	2.2	27.1	5.2	5.46
36-48	0	0.32	0.92	1.04	0.19	9.93	1.5	19.6	4.8	7.10
	1	0.39	0.83	1.37	0.23	10.21	1.7	21.9	4.8	8.97
	2	0.41	1.21	1.26	0.29	9.77	2.2	24.3	5.0	6.50
48-60	0	0.39	0.84	1.09	0.18	9.88	1.5	19.9	4.8	8.00
	1	0.33	0.77	1.41	0.22	11.07	1.6	20.2	4.8	11.06
	2	0.32	0.93	1.13	0.27	10.31	2.1	20.5	4.9	8.28

[1/] Exchangeable sodium percentage.

[2/] Base saturation.

[3/] Extracted with exchangeable bases.

Table 100. Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1966

Depth inches	Wastewater Level inches/week	Exchangeable Cations							pH	Mn3/ µg/g
		K^+	Ca^{2+}	Mg^{2+}	Na^+	H^+	E.S.P.1/ %	B.S.2/ %		
		M.E./100g								
0-12	0	0.64	6.00	0.25	0.15	14.39	0.7	33.9	6.2	3.75
	1	0.72	5.50	0.90	0.46	8.30	2.9	47.7	6.4	3.36
	2	0.54	5.41	1.13	0.50	7.62	3.3	49.9	6.6	2.72
12-24	0	0.41	3.48	0.44	0.13	10.09	0.9	30.7	5.4	3.46
	1	0.36	3.15	0.51	0.30	12.90	1.8	25.1	5.5	3.72
	2	0.51	2.95	0.55	0.32	15.06	1.7	22.3	5.6	3.79
24-36	0	0.39	1.88	0.95	0.11	9.53	0.9	25.5	5.1	4.68
	1	0.35	1.63	1.03	0.19	8 48	1.6	27.4	5.0	6.11
	2	0.44	1.54	0.91	0.23	10.58	1.7	22.8	5.1	6.08
36-48	0	0.57	1.22	1.14	0.10	10.36	0.7	22.6	4.8	6.08
	1	0.43	0.66	1.05	0.16	11.03	1.2	17.4	4.8	5.68
	2	0.38	0.90	1.05	0.20	13.12	1.3	16.2	4.9	6.23
48-60	0	0.48	0.87	1.30	0.12	12.76	0.8	17.8	4.9	6.48
	1	0.51	0.69	1.22	0.16	11.87	1.1	17.9	4.8	7.26
	2	0.57	0.70	1.21	0.20	11.63	1.4	18.7	4.8	7.40

1/ Exchangeable sodium percentage.

2/ Base saturation.

3/ Extracted with exchangeable bases.

Table 101. Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1967

Depth inches	Wastewater Level inches/week	Exchangeable Cations							pH	Mn[3/] µg/g
		K^+	Ca^{2+}	Mg^{2+}	Na^+	H^+	E.S.P.[1/] %	B.S.[2/] %		
				M.E./100g						
0-12	0	0.65	5.15	0.18	0.18	7.67	1.3	44.5	5.9	4.22
	1	0.22	5.32	0.43	0.43	7.95	2.9	46.1	6.4	3.50
	2	0.37	5.23	0.47	0.47	7.07	3.3	50.6	6.4	2.82
12-24	0	0.26	3.12	0.58	0.24	9.45	1.8	30.8	5.5	2.75
	1	0.37	3.32	0.77	0.43	8.48	3.2	36.6	5.7	3.93
	2	0.40	2.99	0.68	0.46	9.32	3.3	32.7	5.5	4.85
24-36	0	0.31	1.81	0.98	0.24	8.97	2.0	27.1	5.2	3.37
	1	0.49	1.94	1.36	0.33	8.85	2.5	31.8	5.2	4.79
	2	0.47	1.54	0.92	0.42	10.11	3.1	24.9	5.1	6.46
36-48	0	0.39	1.11	1.14	0.24	9.31	2.0	23.6	4.9	3.42
	1	0.43	1.48	1.46	0.33	9.25	2.6	28.6	5.1	5.02
	2	0.33	1.07	1.21	0.44	9.68	3.5	24.0	5.0	5.43
48-60	0	0.25	0.96	0.93	0.16	9.06	1.4	20.2	4.9	4.04
	1	0.27	1.06	1.26	0.19	8.55	1.7	24.5	5.0	4.76
	2	0.37	0.80	1.07	0.24	9.43	2.0	20.8	5.0	4.15

[1/] Exchangeable sodium percentage.

[2/] Base saturation.

[3/] Extracted with exchangeable bases.

Table 102. Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1968

Depth inches	Wastewater Level inches/week	Exchangeable Cations							pH	Mn[3/]
		K^+	Ca^{2+}	Mg^{2+}	Na^+	H^+	E.S.P.[1/]	B.S.[2/]		
		M.E./100g					%	%		µg/g
0-12	0	0.50	5.01	0.24	0.25	9.53	1.6	38.6	5.9	3.61
	1	0.46	5.28	1.00	0.47	8.91	2.9	44.7	6.4	2.78
	2	0.62	4.88	1.29	0.54	8.67	3.4	45.8	6.5	2.31
12-24	0	0.59	3.41	0.43	0.26	10.21	1.7	31.5	5.5	2.45
	1	0.24	3.04	0.70	0.39	10.79	2.6	28.8	5.5	3.70
	2	0.18	3.44	0.74	0.47	11.52	2.9	29.5	5.7	2.51
24-36	0	0.36	1.90	0.72	0.18	13.10	1.1	19.4	5.0	3.03
	1	0.18	1.74	1.15	0.29	12.05	1.9	21.8	5.2	4.34
	2	0.31	2.12	1.04	0.40	12.04	2.5	24.3	5.3	3.57
36-48	0	0.57	1.31	0.95	0.20	12.84	1.3	19.1	5.0	2.12
	1	0.46	1.50	1.40	0.30	12.38	1.9	22.8	5.0	3.64
	2	0.26	1.64	1.25	0.36	11.73	2.4	23.0	5.1	4.36
48-60	0	0.34	0.95	0.99	0.19	11.90	1.3	17.2	4.9	2.30
	1	0.42	1.26	1.63	0.31	13.38	1.8	21.3	4.9	4.06
	2	0.44	1.17	1.20	0.33	13.01	2.0	19.4	5.0	4.98

[1/] Exchangeable sodium percentage.

[2/] Base saturation.

[3/] Extracted with exchangeable bases.

Table 103. Chemical Characteristics of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater. 1969

Depth inches	Wastewater Level inches/week	Exchangeable Cations							pH	Mn[3/]
		K^+	Ca^{2+}	Mg^{2+}	Na^+	H^+	E.S.P.[1/]	B.S.[2/]		
		M.E./100g					%	%		µg/g
0-12	0	0.15	4.98	0.26	0.21	10.79	1.3	34.2	5.6	7.61
	1	0.42	5.75	1.11	0.43	9.92	2.3	43.7	6.3	4.03
	2	0.59	5.65	1.40	0.44	9.79	2.5	45.2	6.3	4.35
12-24	0	0.10	3.25	0.34	0.19	10.69	1.3	26.6	5.1	3.35
	1	0.18	4.14	0.68	0.42	10.01	2.7	35.1	5.8	2.63
	2	0.24	3.64	0.80	0.43	10.06	2.8	33.7	5.6	3.97
24-36	0	0.33	2.30	0.74	0.18	11.54	1.2	23.5	5.1	4.55
	1	0.09	2.48	1.17	0.29	11.76	1.8	25.5	5.1	5.40
	2	0.14	2.09	1.02	0.37	11.75	2.4	23.6	5.2	6.75
36-48	0	0.28	1.89	0.89	0.16	12.46	1.0	20.5	5.0	4.12
	1	0.18	1.92	1.30	0.28	12.76	1.7	22.4	5.1	5.61
	2	0.25	1.34	1.28	0.30	13.04	1.8	19.6	5.1	6.20
48-60	0	0.54	1.45	0.99	0.19	11.18	1.3	22.1	4.9	4.06
	1	0.40	1.74	1.43	0.20	12.25	1.2	23.5	5.0	7.28
	2	0.33	1.02	1.24	0.32	11.38	2.2	20.4	4.9	6.67

[1/] Exchangeable sodium percentage.

[2/] Base saturation.

[3/] Extracted with exchangeable bases.

Table 104. Chemical Characteristics of Soil Samples at Five Depths from the Reed Canarygrass Area Which Received Two Inches of Wastewater Per Week. 1969

	Exchangeable Cations												
Depth inches	K^+	Ca^{2+}	Mg^{2+}	Na^+	H^+	E.S.P.[1/] %	B.S.[2/] %	N %	O.M. %	Mn[3/]	B[3/]	Cl	pH
	M.E. 100/g									µg/g			
0-12	0.33	5.72	1.17	0.48	9.91	2.7	43.7	0.133	3.01	4.72	0.63	59.4	6.4
12-24	0.06	3.25	0.89	0.45	11.26	2.8	29.2	0.048	0.82	12.60	0.26	49.7	5.7
24-36	0.34	2.04	1.27	0.44	12.45	2.7	24.7	0.032	0.34	9.49	0.19	57.7	5.4
36-48	0.32	1.63	1.32	0.27	12.22	1.7	22.5	0.022	0.18	7.99	0.29	53.5	5.2
48-60	0.53	1.25	1.43	0.26	11.28	1.8	23.5	0.021	0.09	5.26	0.63	56.5	5.0

[1/] Exchangeable sodium percentage.

[2/] Base saturation.

[3/] Extracted with exchangeable bases.

Table 105. Chemical Characteristics of Soil Samples at Five Depths from Plots of the Hardwood Area on Morrison Sandy Loam Soil at the Gamelands Which Received 0 and 2 Inches of Wastewater Weekly. 1967

Soil Depth inches	Wastewater Level inches/week	Exchangeable Cations										
		K^+	Ca^{2+}	Mg^{2+}	Na^+	H^+	E.S.P.[1]	B.S.[2]	Mn[3]	B[3]	Cl	pH
		M.E./100g					%	%	µg/g			
0-12	0	0.08	0.34	0.00	0.16	5.20	2.8	10.0	12.6	0.40	43.3	4.9
	2	0.15	0.91	0.18	0.27	4.15	4.8	26.7	6.8	0.45	40.4	5.5
12-24	0	0.24	0.36	0.00	0.16	3.75	3.5	16.8	7.8	0.60	43.3	5.0
	2	0.24	0.50	0.09	0.21	1.85	7.3	36.0	4.6	0.55	48.7	5.3
24-36	0	0.25	0.45	0.09	0.19	3.45	4.3	22.1	4.4	0.10	32.4	5.4
	2	0.25	0.86	0.35	0.26	2.65	5.9	39.4	6.2	0.15	37.8	5.5
36-48	0	0.43	0.34	0.07	0.16	2.75	4.3	26.7	5.1	0.35	24.6	5.4
	2	0.46	1.19	0.63	0.24	2.75	4.6	47.8	4.4	0.45	21.7	5.9
48-60	0	0.33	0.30	0.05	0.18	1.65	7.2	34.3	4.6	0.35	29.7	5.4
	2	0.44	1.20	0.63	0.24	3.80	3.8	39.8	4.7	0.45	29.4	5.7

[1] Exchangeable sodium percentage.

[2] Base saturation.

[3] Extracted with exchangeable bases.

Table 106. Chloride Content of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater.

Depth inches	Wastewater Level inches/week	Chloride[1]-micrograms per gram					
		1963	1965	1966	1967	1968	1969
0-12	0	20.3	7.7	31.1	29.9	36.0	44.1
	1	27.4	24.6	35.2	40.2	40.6	41.2
	2	27.9	16.6	37.6	53.4	37.2	46.6
12-24	0	16.6	12.8	25.8	27.7	29.4	44.1
	1	36.6	19.9	31.4	37.6	37.6	45.7
	2	38.1	15.6	33.8	41.1	43.5	48.4
24-36	0	27.2	12.5	44.7	37.1	38.1	47.3
	1	40.6	49.5	59.0	41.3	44.1	50.0
	2	45.7	36.1	58.6	39.0	39.6	58.8
36-48	0	41.5	12.5	33.3	46.5	38.5	40.4
	1	33.0	32.1	63.8	60.9	43.9	55.2
	2	65.7	37.8	70.6	69.0	62.0	69.7
48-60	0	26.8	23.6	26.2	53.8	31.6	49.4
	1	29.2	31.5	47.8	59.9	56.2	67.1
	2	42.0	36.4	61.5	66.2	61.6	80.2

[1] Extracted with 0.05 Normal ammonium nitrate.

Table 107. Boron Content of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater.

Depth inches	Wastewater Level inches/week	Boron[1]-micrograms per gram				
		1963	1965	1967	1968	1969
0-12	0	0.75	1.03	0.63	0.48	0.12
	1	0.68	1.23	0.50	0.71	0.61
	2	1.07	0.80	0.84	0.83	0.80
12-24	0	0.53	1.10	0.50	0.70	0.08
	1	0.57	1.23	0.61	0.28	0.22
	2	0.56	1.36	0.80	0.49	0.32
24-36	0	0.42	1.31	0.24	0.36	0.22
	1	0.39	1.16	0.50	0.36	0.24
	2	0.38	1.15	0.72	0.45	0.13
36-48	0	1.68	0.92	0.35	0.38	0.24
	1	1.41	1.13	0.38	0.15	0.14
	2	0.87	1.22	0.64	0.32	0.32
48-60	0	1.76	0.75	0.37	0.38	0.64
	1	1.73	0.80	0.24	0.60	0.34
	2	1.55	0.96	0.47	0.54	0.48

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[1] Boron extracted during extraction of exchangeable bases.

Table 108. Nitrogen and Organic Matter Content of Soil Samples at Five Depths from Plots of the Corn Rotation Area Receiving Various Levels of Wastewater.

Depth inches	Wastewater Level inches/week	Nitrogen - %				Organic Matter - %		
		Year				Year		
		1963	1965	1966	1968	1963	1965	1968
0-12	0	0.113	0.090	0.121	0.109	2.75	2.52	3.08
	1	0.131	0.090	0.130	0.108	2.51	2.10	2.60
	2	0.094	0.091	0.137	0.106	2.41	2.06	2.84
12-24	0	0.050	0.026	0.058	0.038	0.42	0.52	0.91
	1	0.038	0.027	0.063	0.032	0.42	0.57	0.36
	2	0.037	0.032	0.069	0.032	0.32	0.67	0.58
24-36	0	0.024	0.020	0.031	0.025	0.21	0.16	0.44
	1	0.024	0.015	0.024	0.022	0.20	0.13	0.33
	2	0.025	0.015	0.032	0.018	0.17	0.19	0.21
36-48	0	0.016	0.016	0.026	0.018	0.22	0.12	0.15
	1	0.016	0.014	0.020	0.021	0.14	0.13	0.24
	2	0.015	0.018	0.025	0.021	0.14	0.12	0.18
48-60	0	0.016	0.013	0.019	0.013	0.13	0.11	0.11
	1	0.014	0.015	0.012	0.013	0.09	0.14	0.17
	2	0.014	0.014	0.015	0.017	0.11	0.16	0.15

Soil Phosphorus Relationships

Previous Work. The removal of phosphorus by soil from a solution in contact with it is widely believed to be due to adsorption. This conclusion is supported by the fact that various investigators have found that the pattern of removal of phosphorus from solution closely agreed with the Langmuir adsorption isotherm (58, 59, 60).

The Langmuir (61) equation was originally applied to the adsorption of gases on plane surfaces but has since been used successfully to explain the pattern of adsorption of many substances from solution. The Langmuir equation,

$$\frac{x}{m} = \frac{Kbc}{1 + Kc} , \qquad (1)$$

may be written in its linear form,

$$\frac{c}{x/m} = \frac{1}{Kb} + \frac{c}{b} \qquad (2)$$

where

c = equilibrium concentration,

x/m = amount of adsorbate per unit weight of adsorbent

K = constant relating the bonding energy of the adsorbent for the adsorbate,

b = adsorption maximum or the amount adsorbed when all sites are occupied

Langmuir in the development of this equation had made certain assumptions: firstly, that there were on the surface of the adsorbent, discrete points at which adsorption could occur and, secondly, that each of these points could independently hold only one adsorbed molecule. He suggested that any anomalous behavior might be due to (1) porous bodies that would cause internal adsorption; (2) condensation, if the vapor was saturated; and (3) solution or absorption being mistaken for adsorption.

A number of workers have also found conformity of phosphorus adsorption with the Freundlich adsorption isotherm (62, 63, 64).

The Freundlich adsorption equation relates the amount of adsorbate to the final concentration of the solution from which adsorption occurs. It is

$$\frac{x}{m} = KC^{1/n} \qquad (3)$$

or written in linear form is

$$\log \frac{x}{m} = \log K + \frac{1}{n} \log C \qquad (4)$$

where

x/m = amount of adsorbate per unit weight of adsorbent

C = equilibrium concentration

K and n are constants

According to the Freundlich equation, the amount adsorbed increases indefinitely with increasing concentration or pressure. A linear plot of the logarithmic form of the equation is called a Freundlich adsorption isotherm.

The Freundlich equation is an empirical one, having been deduced from thermodynamic considerations, using empirical methods for determining the change in surface tension with changes in concentration. It, therefore, does not give any insight into the mechanism of adsorption nor is it satisfactory for high coverages. However, it is sometimes more successful than the Langmuir equation from the empirical standpoint. The Langmuir equation furthermore is not a satisfactory representation of physical-adsorption data. It has been found for example that at apparent saturation of the surface, only a small percentage of the total area is covered (65). This deviation would result from a heterogeneous surface, that is, a surface on which different regions have different affinities for the substances being adsorbed.

In comparing both equations for use in the adsorption of phosphorus by soils, Olsen and Watanabe (60) stated that the Langmuir equation was more applicable to relatively small amounts of adsorbed phosphorus and thus at lower equilibrium concentrations. The Freundlich equation, on the other hand, was applicable to a wide range of equilibrium concentrations. The Langmuir equation, unlike that of Freundlich, enabled one to calculate the adsorption maximum which was found to be closely correlated with surface area. In addition, Olsen and Watanabe (60) and Hsu and Rennie (66) obtained results that indicated that both adsorption isotherms were followed. It was noted, however (60), that the adsorption pattern agreed more closely with the Langmuir adsorption isotherm.

Various equilibration periods have been used. Russel and Low (64) employed a period of one hour while Hsu (59), Rennie and McKercher (67) and Weir and Soper (68) used an equilibration period of six hours. Other investigators (60) have reported an equilibration period of 24 hours but Seatz (69) used seven days and that in the study by Davis (62) was 16 days. The latter author found a slow attainment of equilibrium even after this time and suggested that other processes besides adsorption were occurring since the equilibrium resulting from adsorption is supposed to be a rapid one.

A change in the slope of the adsorption isotherm plotted by Olsen and Watanabe (60) occurred at equilibrium concentrations in the range $4\text{-}7 \times 10^{-4}$ moles/ℓ(12-22 mg/ℓ). Similar observations were made by Rennie and McKercher (67) at a final concentration of 20 mg/ℓ, and by Weir and Soper (68) at around 30 mg/ℓ. The isotherms plotted above these concentrations were all lower in slope than the isotherms plotted at the lower concentrations and adsorption maxima calculated from them were considerably higher than those given for the initial adsorption reaction. It is suggested (68) that this secondary reaction could be either a true adsorption or precipitation. On the other hand, it was thought (67) that this anomaly indicated that either new centers of adsorption had been found or multi-molecular adsorption had occurred.

Although the adherence of phosphorus adsorption to the Langmuir and Freundlich isotherms probably indicates adsorption of a monomolecular layer, it does not necessarily imply an adsorption reaction. Hsu (59) maintains that the application of the Langmuir adsorption isotherm to phosphorus fixation is subject to certain limitations namely, pH of the solution, absence of exchangeable aluminum and the equilibration period. When phosphorus solution at pH 7 was shaken for a relatively short period (6 hours) with slightly acid soil in the absence of exchangeable aluminum then adsorption occurred and the Langmuir adsorption isotherm was followed. Fixation, he pointed out, would be very slow unless the reaction was carried out in a strongly acidic medium or if exchangeable aluminum was present.

Davis (62) also stated that adherence to the Freundlich adsorption isotherm did not necessarily imply that fixation was due to adsorption. The slow rate of reversal of fixation made adsorption doubtful as a fixation process.

The fixation of phosphorus has been found to be inversely related to the amount of organic matter present in the soil (70, 71). Expressed differently, the addition of organic matter to the soil significantly reduced the fixation of phosphorus and simultaneously increased its availability. Doughty (71) also found that although a soil naturally low in organic matter had a high phosphorus fixing capacity, the oxidation of organic matter with hydrogen peroxide caused a decrease in the fixation of phosphorus. Loss of fixing power was attributed to the saturation of the fixing material with the phosphate liberated from the organic matter during oxidation.

Swenson et al. (72) stated that organic matter prevented phosphorus from combining with iron and aluminum and caused the release of combined phosphorus by the formation of stable iron and aluminum complexes with the organic acids produced by decomposition of the organic matter.

Phosphorus Adsorption Studies. In May, 1965 soil samples were obtained from the corn rotation control area for use in a phosphorus adsorption study (8). The samples were taken randomly from the 240 x 800 foot area using a manually operated soil augur. The material from one-foot intervals to a depth of five feet was composited to give bulk samples, one for each depth interval. Some physical and chemical characteristics of these samples is shown in Table 109. These same materials were also used in ABS and cation adsorption studies.

Five gram samples of <2.0mm sieve size were shaken for 24 hours with 50 ml of KH_2PO_4 solutions containing 15, 30, 40, 60, 100, 125, 150 and 200 mg P per liter. After centrifuging, the supernatant solution was analyzed for P using the sulfuric-molybdate procedure in Jackson (73, pg 141). The same adsorption procedure was used with the same soil which had been treated with hydrogen peroxide to remove organic matter. The oxidized sample was washed three times by centrifugation and decantation with distilled water and then air dried before being used in the adsorption studies.

Adsorption data for untreated and treated (H_2O_2 oxidized) soil from the five depths are shown in Tables 110 and 111. The data plotted according to the Langmuir adsorption equation are shown in Figures 58 through 62.

At each depth the data appeared to conform to two adsorption isotherms, the one at the higher concentrations being less steep in slope. For untreated and treated soil from the 1-foot zone, which had the highest organic matter content, the break in slope occurred at an equilibrium concentration of 15.5 mg P per liter (0.5 millimoles P per liter). For samples deeper in the profile the break in slope occurred at lower equilibrium concentrations, ranging down to about 6.5 mg P per liter (0.2 millimoles P per liter).

Other workers have also reported the presence of bi-modal adsorption isotherms. Olsen and Watanabe (60) found that for different soils the first isotherm terminated at concentrations ranging from 12 to 25 mg P per liter. Weir and Soper (68) also reported initial adherence to the Langmuir isotherm only at final concentrations below 25-30 mg P per liter.

Adsorption maxima computed from the initial isotherms were smaller than those computed from the second isotherm. Since the initial isotherm is believed to represent the reversible, instantaneous surface reaction defined by the Langmuir concept, only the adsorption maximum computed from this isotherm can be mathematically justified. The

Table 109. Physical and Chemical Characteristics of Soil Samples from Control Plots of the Corn Rotation Area (8)

Depth (inches)	Sand (%)	Silt (%)	Clay (%)	Organic Matter (%)	pH	Acid-Sol[1/] P (ppm)	Exchangeable Cations (me/ 100g)				
							H^+	Ca^{2+}	Mg^{2+}	K^+	Na^+
0-12	33.0	34.4	32.6	3.34	5.6	3.50	6.95	5.60	0.42	0.18	0.25
12-24	28.3	31.7	40.0	0.93	4.7	1.75	8.66	3.40	0.73	0.18	0.20
24-36	28.0	23.9	48.1	0.48	4.6	1.75	6.95	2.60	1.33	0.21	0.17
36-48	27.8	23.6	48.6	0.25	4.5	1.50	10.22	1.80	1.25	0.21	0.19
48-60	29.3	20.7	50.0	0.19	4.5	1.50	7.80	1.60	1.25	0.22	0.22

[1/] Dilute Bray, 0.03N·NH_4F in 0.025 N·HCl, extractable.

Table 110. Equilibrium Concentration (mmole/ℓ) and Phosphorus Adsorbed (mg/g) by Untreated Soil[1] from Various Depths (8)

Depth of Sampling, Inches									
0-12		12-24		24-36		36-48		48-60	
Eq Conc	P Ads	Eq Conc	P Ads	Eq Conc	P Ads	Eq Conc	P Ads	Eq Conc	P Ads
0.0363	0.1478	0.0114	0.3025	0.0323	0.4000	0.0123	0.3022	0.0131	0.3019
0.1581	0.2571	0.0452	0.3960	0.0645	0.4600	0.0452	0.3960	0.0452	0.3960
0.3097	0.3141	0.1065	0.4470	0.1581	0.5710	0.1129	0.4450	0.1161	0.4440
0.5065	0.3231	0.1952	0.5595	0.6387	0.7920	0.1855	0.5625	0.2371	0.5465
0.7677	0.3821	0.7806	0.7480	1.1387	0.9020	0.6387	0.7920	0.7419	0.7600
1.6645	0.4741	1.3452	0.8380	1.6774	0.9400	1.3194	0.8460	1.3581	0.8340
2.1806	0.5791	1.8065	0.9000	2.8871	1.0250	1.6774	0.9400	1.7258	0.9250
3.0742	0.5071	2.9839	0.9950	4.2581	1.1900	2.8387	1.0400	2.8871	1.0250
4.4194	0.5501	4.5484	1.1000	---	---	4.3871	1.1500	4.5161	1.1100

---

[1] Not treated with hydrogen peroxide.

Table 111. Equilibrium Concentration (mmole/ℓ) and Phosphorus Adsorbed (mg/g) by Treated Soil[1] from Various Depths (8)

Depth of Sampling, Inches									
0-12		12-24		24-36		36-48		48-60	
Eq Conc	P Ads	Eq Conc	P Ads	Eq Conc	P Ads	Eq Conc	P Ads	Eq Conc	P Ads
0.0645	0.1263	0.0266	0.2917	0.0161	0.2950	0.0160	0.2950	0.0155	0.2950
0.2161	0.2330	0.1032	0.3780	0.0839	0.3840	0.0645	0.3900	0.0516	0.3840
0.4194	0.2800	0.2194	0.4260	0.1548	0.4460	0.1935	0.4340	0.1935	0.4340
0.5484	0.3240	1.1742	0.6360	0.9290	0.7320	0.9806	0.6960	1.0000	0.6900
1.6452	0.4900	2.4032	0.7550	2.0968	0.8500	2.1613	0.8300	2.2097	0.8150
2.9839	0.5750	3.8064	0.8600	3.3871	0.9900	3.5484	0.9400	3.5000	0.9550

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[1] Treated with hydrogen peroxide to remove organic matter.

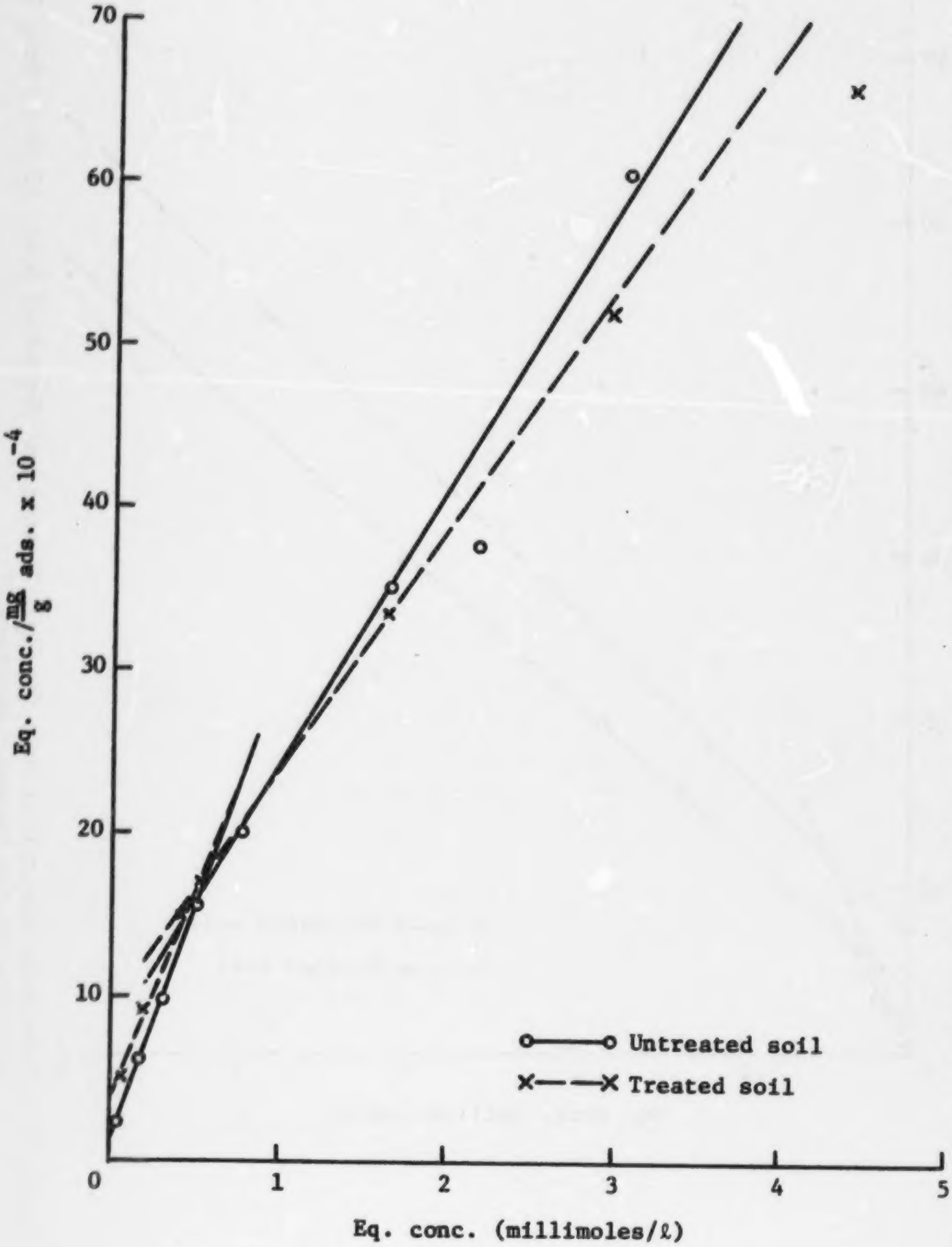

Figure 58. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 0-12 inches, Plotted According to the Langmuir Equation (8).

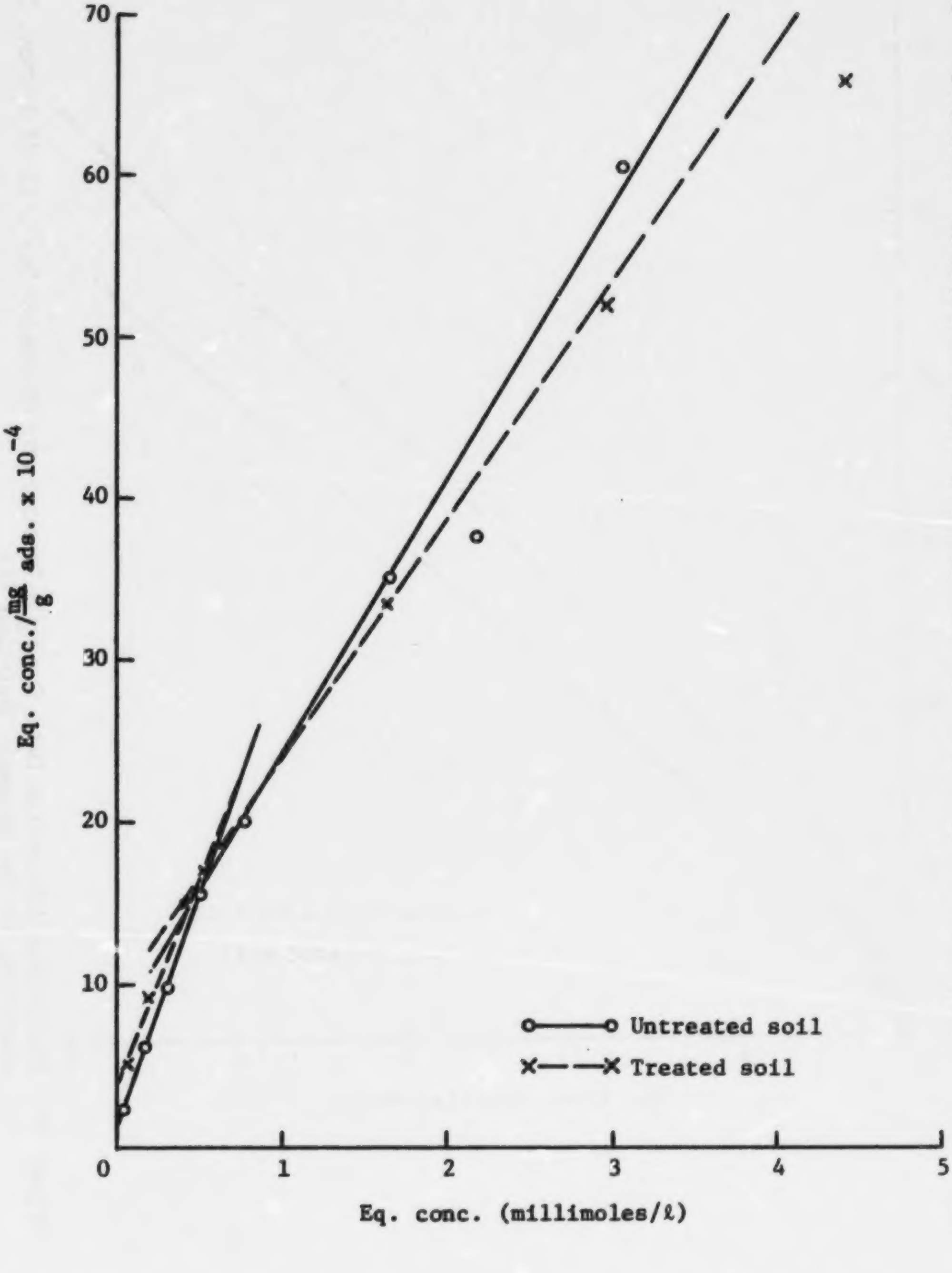

Figure 58. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 0-12 inches, Plotted According to the Langmuir Equation (8).

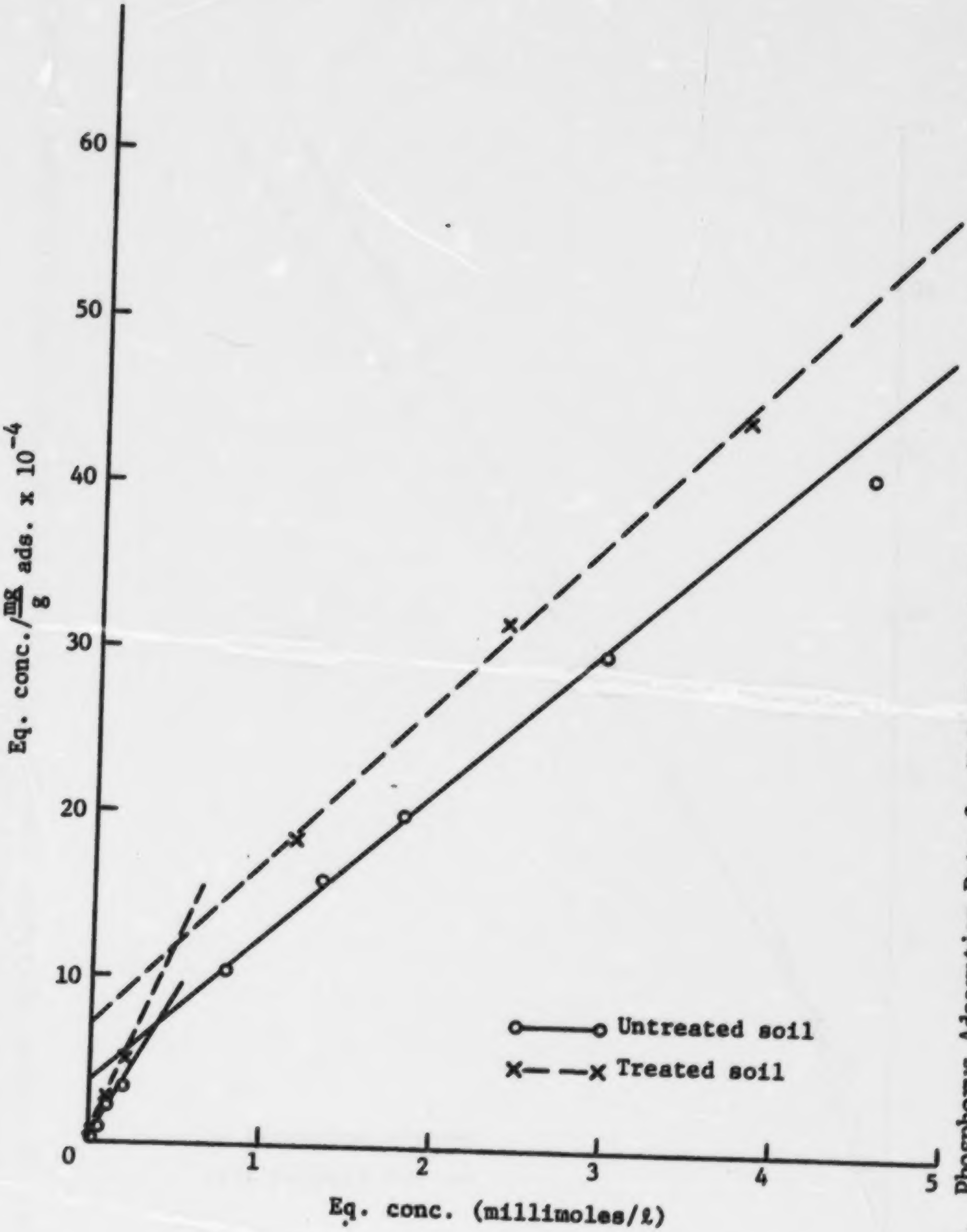

Figure 59. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 12-24 inches, Plotted According to the Langmuir Equation (8).

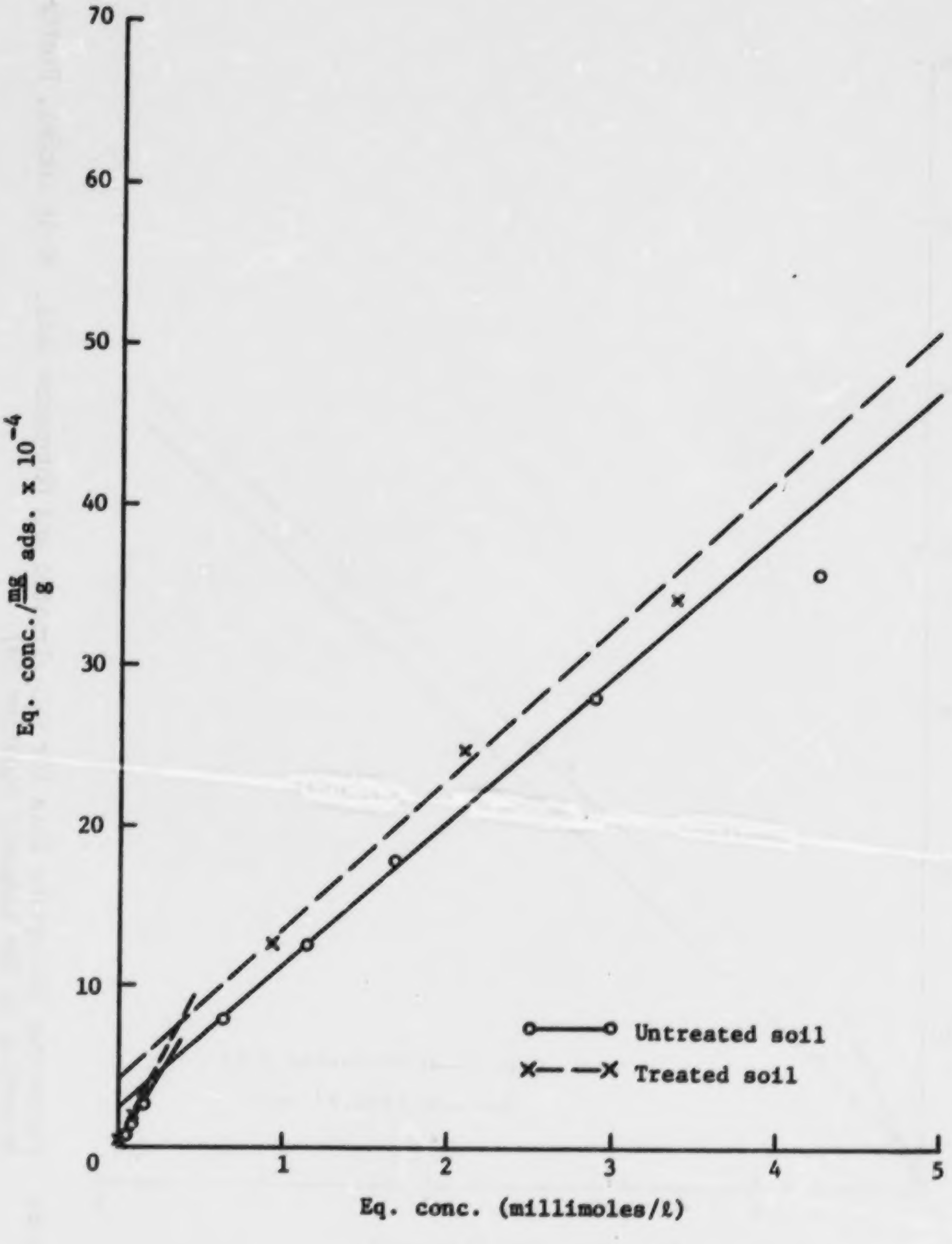

Figure 60. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 24-36 inches, Plotted According to the Langmuir Equation (8).

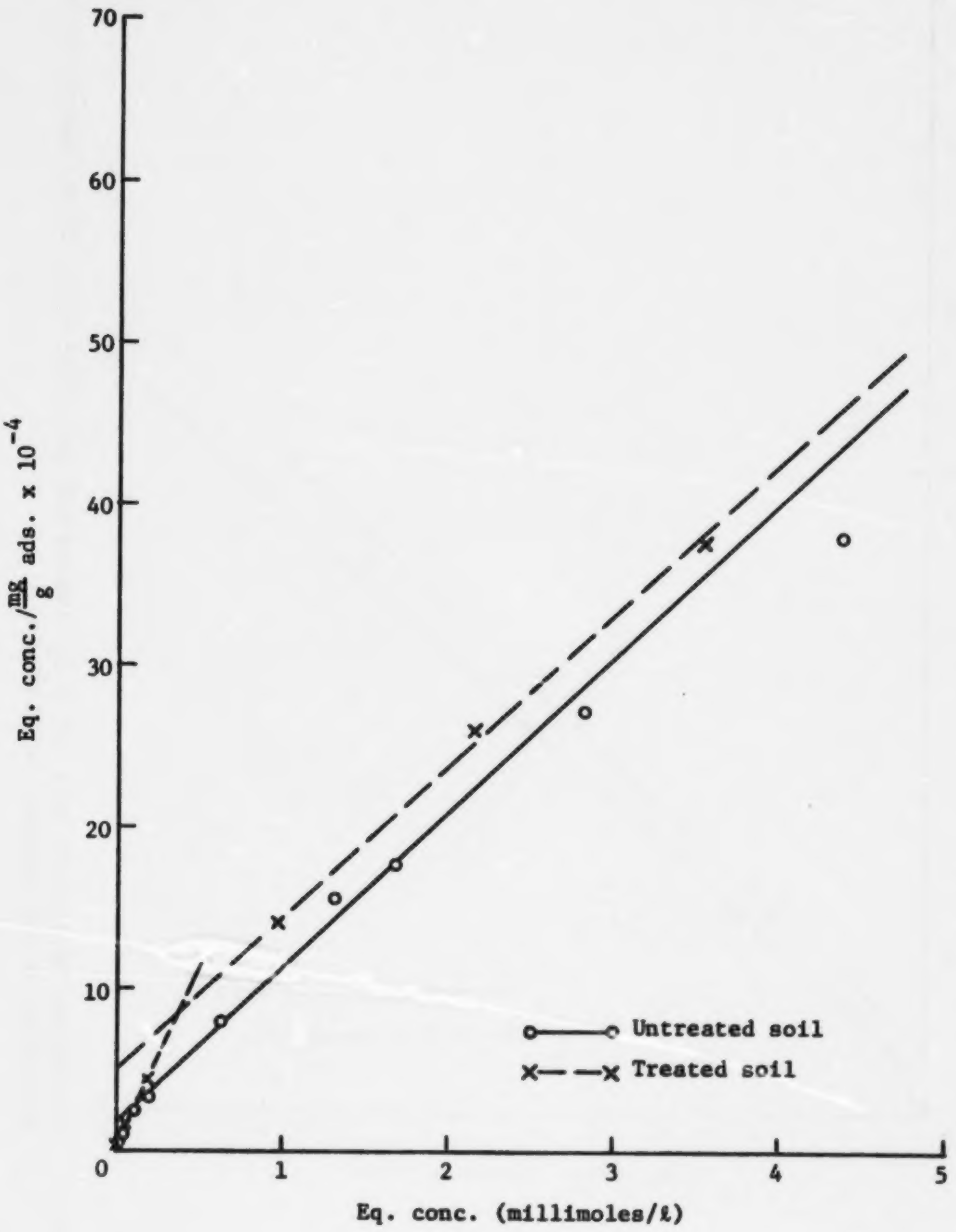

Figure 61. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 36-48 inches, Plotted According to the Langmuir Equation (8).

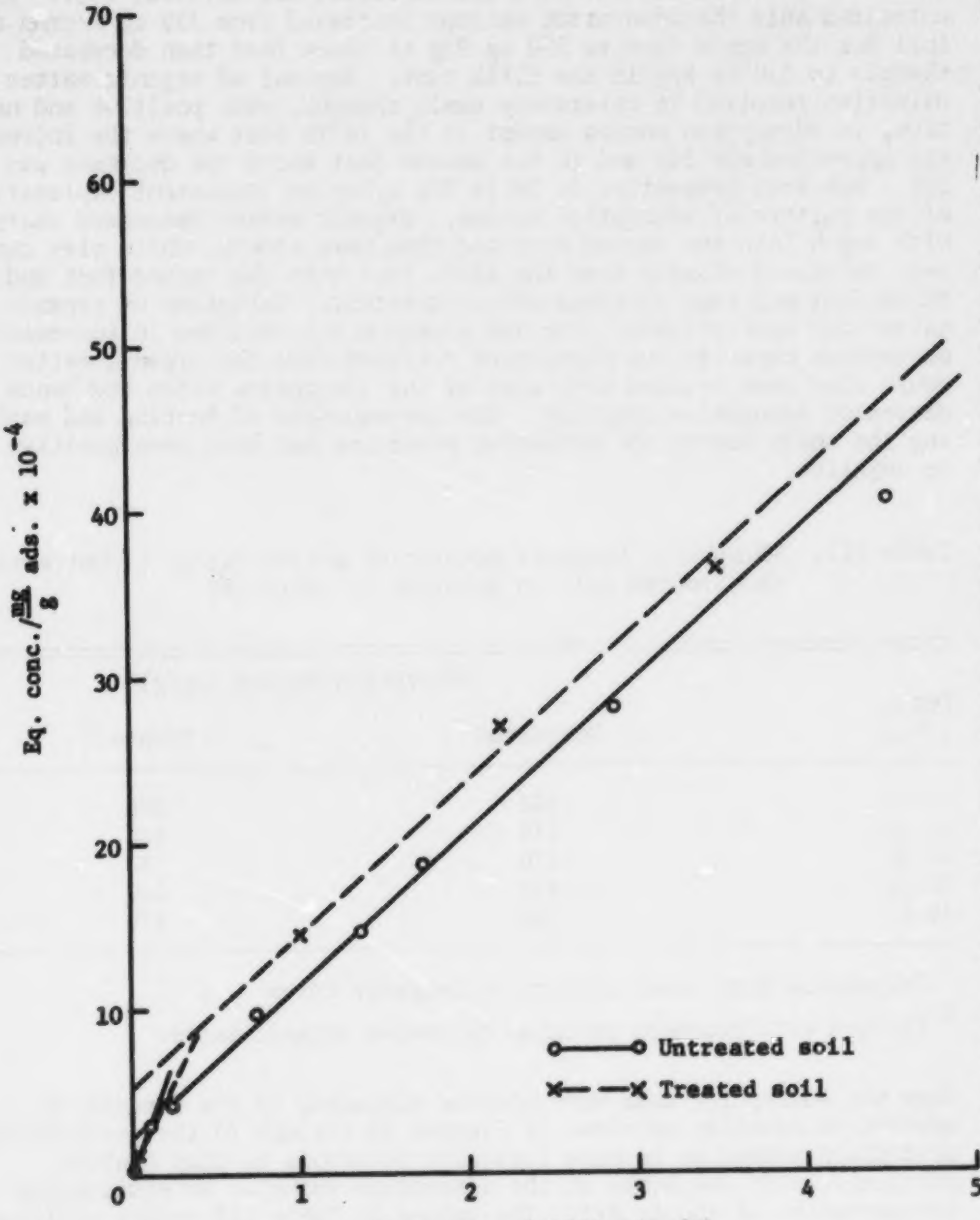

Figure 62. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 48-60 inches, Plotted According to the Langmuir Equation (8).

second isotherm is believed to be associated with a slower, continuing, less-reversible reaction with oxy- and hydroxy compounds of iron and aluminum. The adsorption maxima computed from the initial isotherm are shown in Table 112 for both the untreated and oxidized soil. In untreated soil the adsorption maximum increased from 350 μg P/gram of soil for the upper foot to 570 μg P/g at three feet then decreased sharply to 350 μg P/g in the fifth foot. Removal of organic matter by oxidation resulted in relatively small changes, both positive and negative, in adsorption maxima except in the fifth foot where the increase was approximately 34% and in the second foot where the decrease was 22%. The soil properties in Table 109 offer no consistent explanation of the pattern of adsorption maxima. Organic matter decreased sharply with depth into the second foot and then more slowly, while clay content increased sharply from the first foot into the second foot and third foot and then remained almost constant. Oxidation of organic matter may have released iron and aluminum and resulted in increased adsorption capacity but phosphorus released from the organic matter could also have reacted with some of the adsorption sites and hence decreased adsorption capacity. The consequences of heating and washing the soils during the oxidation procedure may have been positive or negative.

Table 112. Phosphorus Langmuir Adsorption Maxima (μg/g) of Untreated and Treated Soil in Relation to Depth (8)

Depth (in.)	Adsorption Maxima (μg/g)[1] Untreated	Treated[2]
0-12	350	390
12-24	540	420
24-36	570	530
36-48	450	460
48-60	350	470

[1] Calculated from lower portion of Langmuir curve

[2] Treated with hydrogen peroxide to remove organic matter

When the adsorption data were plotted according to the Freundlich adsorption equation as shown in Figures 63 through 67 the patterns of adsorption seemed to be more logically relatable to clay content, particularly if one looks at the adsorption value at an equilibrium concentration of 100 mg P/1. The values in Table 113 relate positively to clay content and negatively with respect to organic matter content in the untreated soil and the soil with the greatest amount of organic

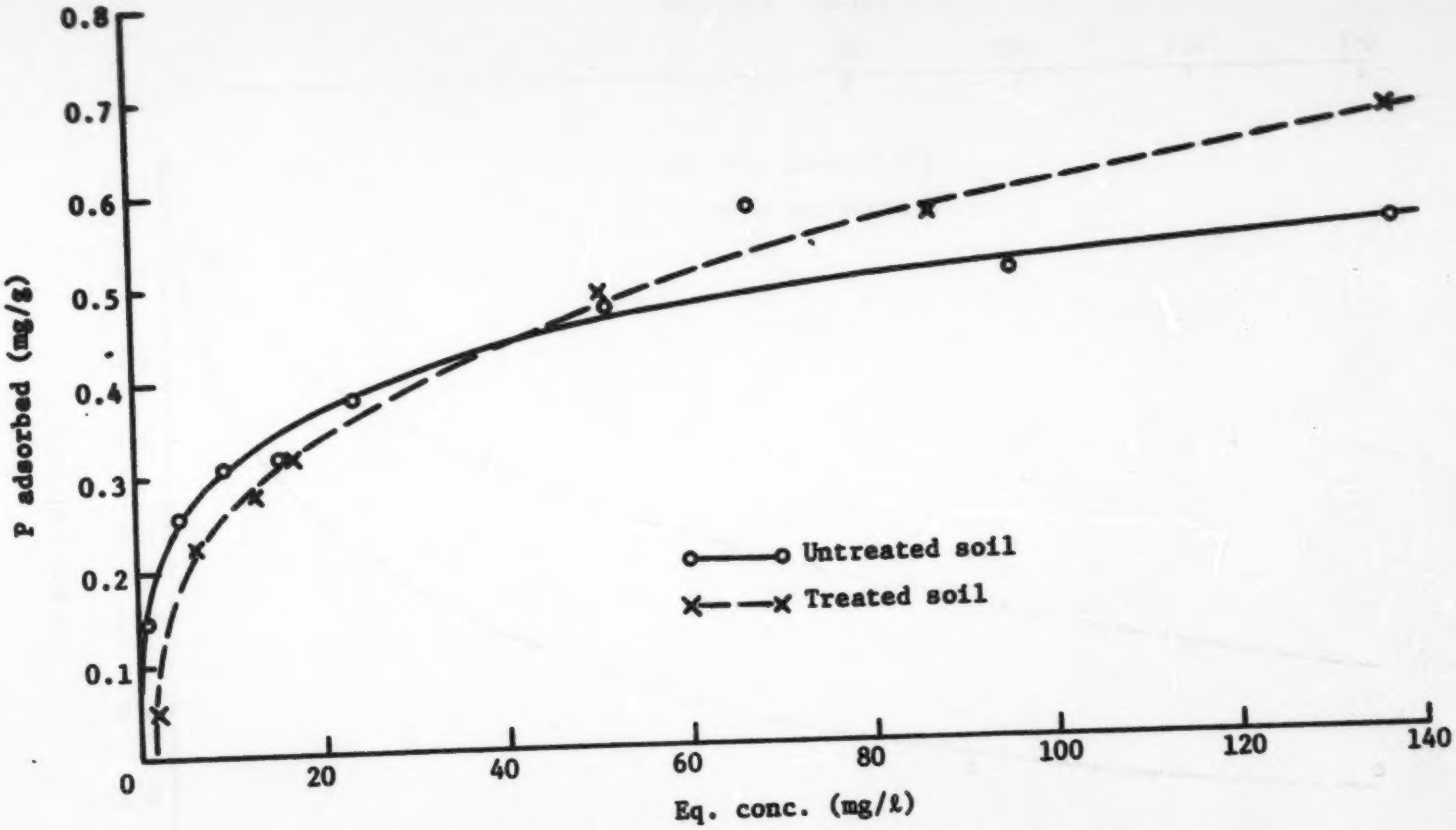

Figure 63. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 0-12 Inches, Plotted According to the Freundlich Equation (8).

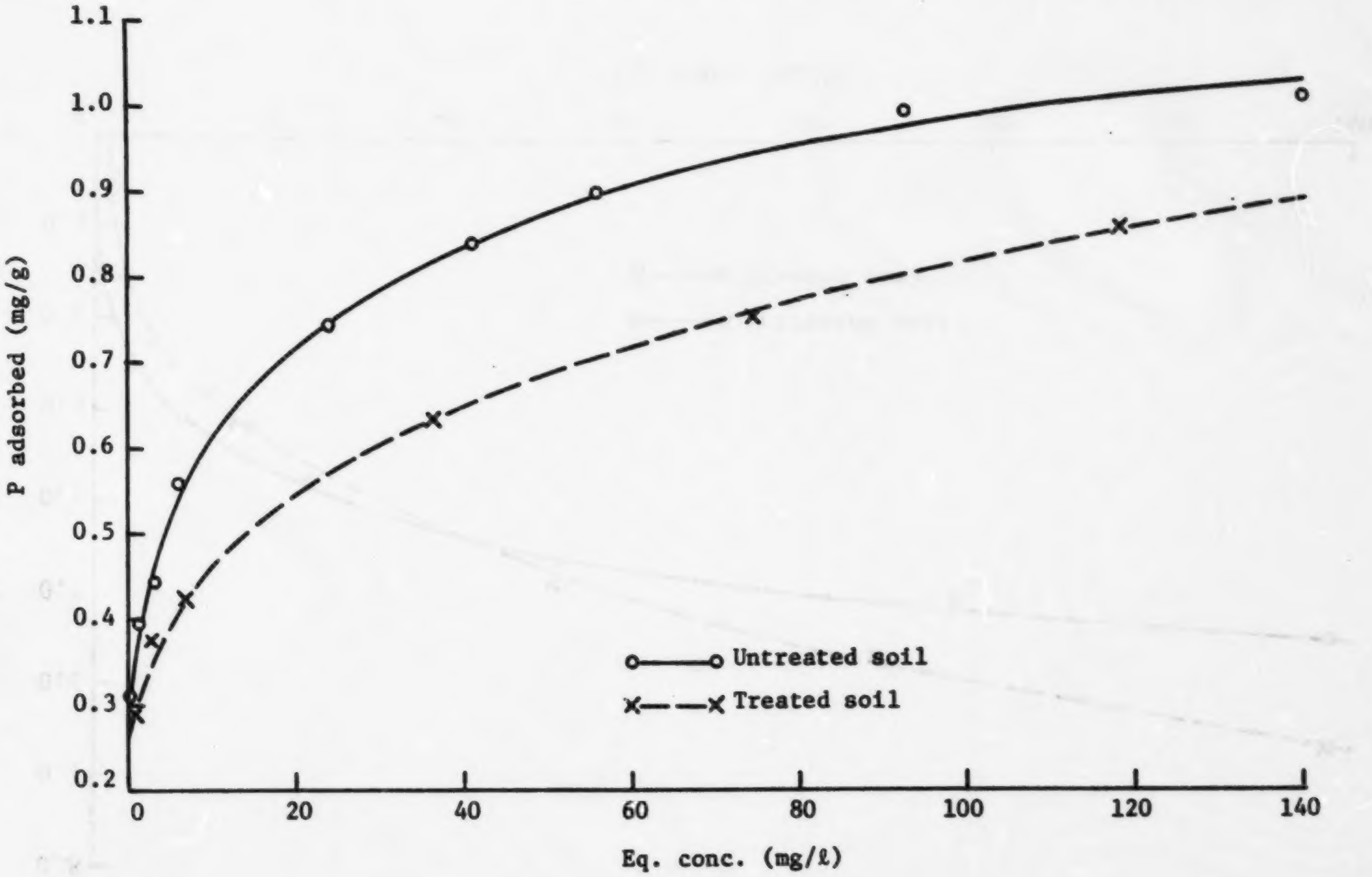

Figure 64. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 12-24 inches, Plotted According to the Freundlich Equation (8).

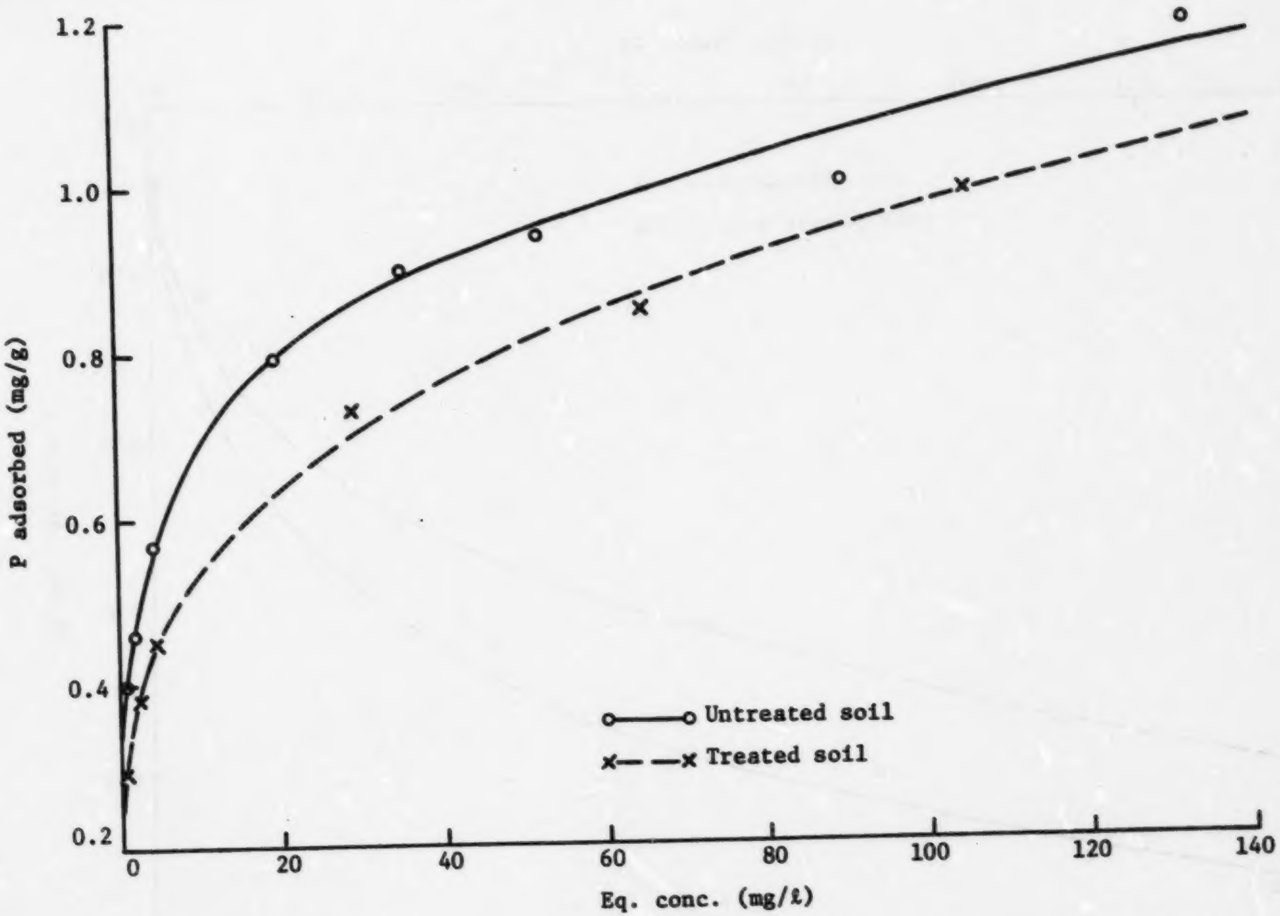

Figure 65. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 24-36 inches, Plotted According to the Freundlich Equation (8).

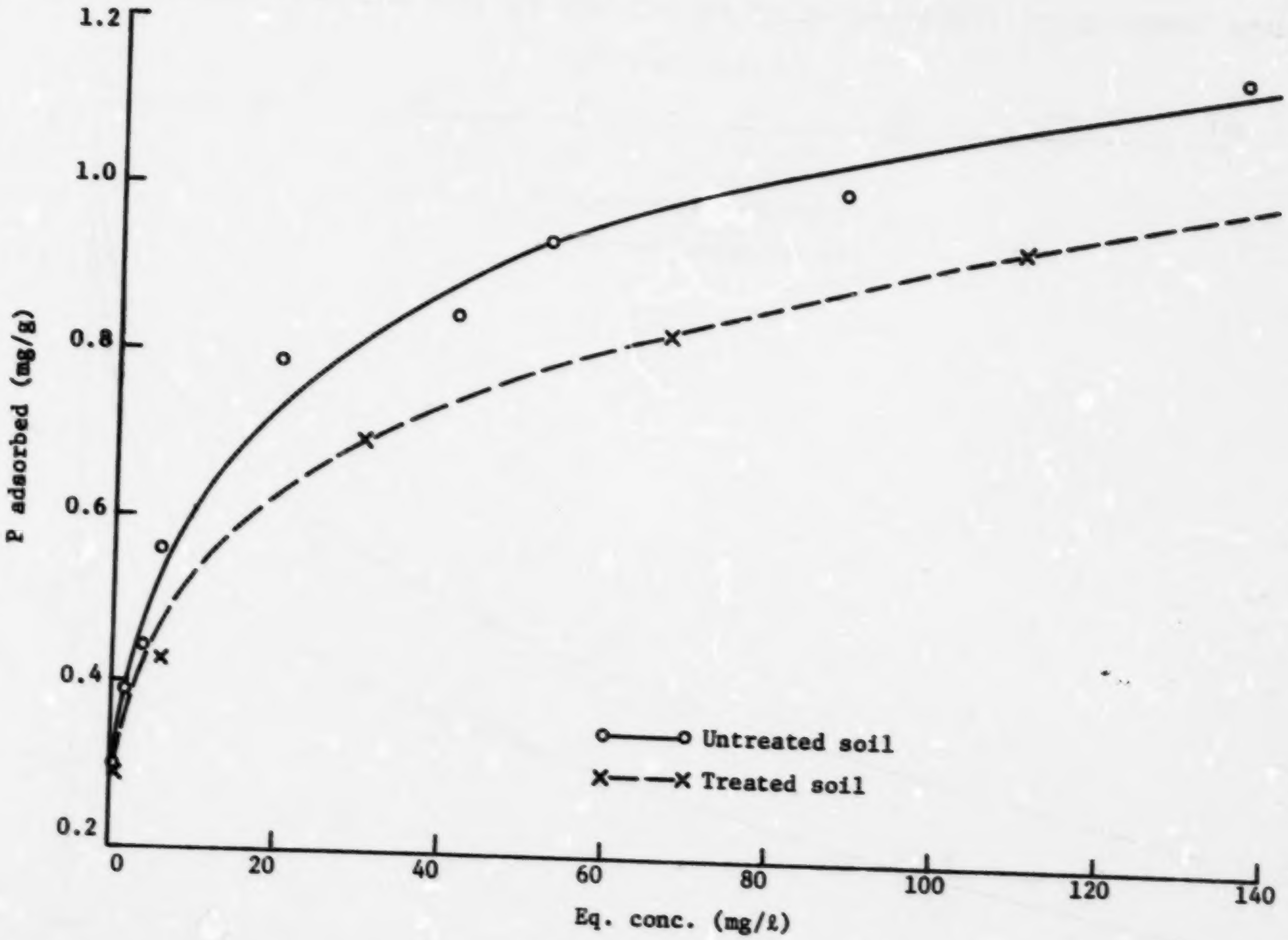

Figure 66. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 36-48 inches, Plotted According to the Freundlich Equation (8).

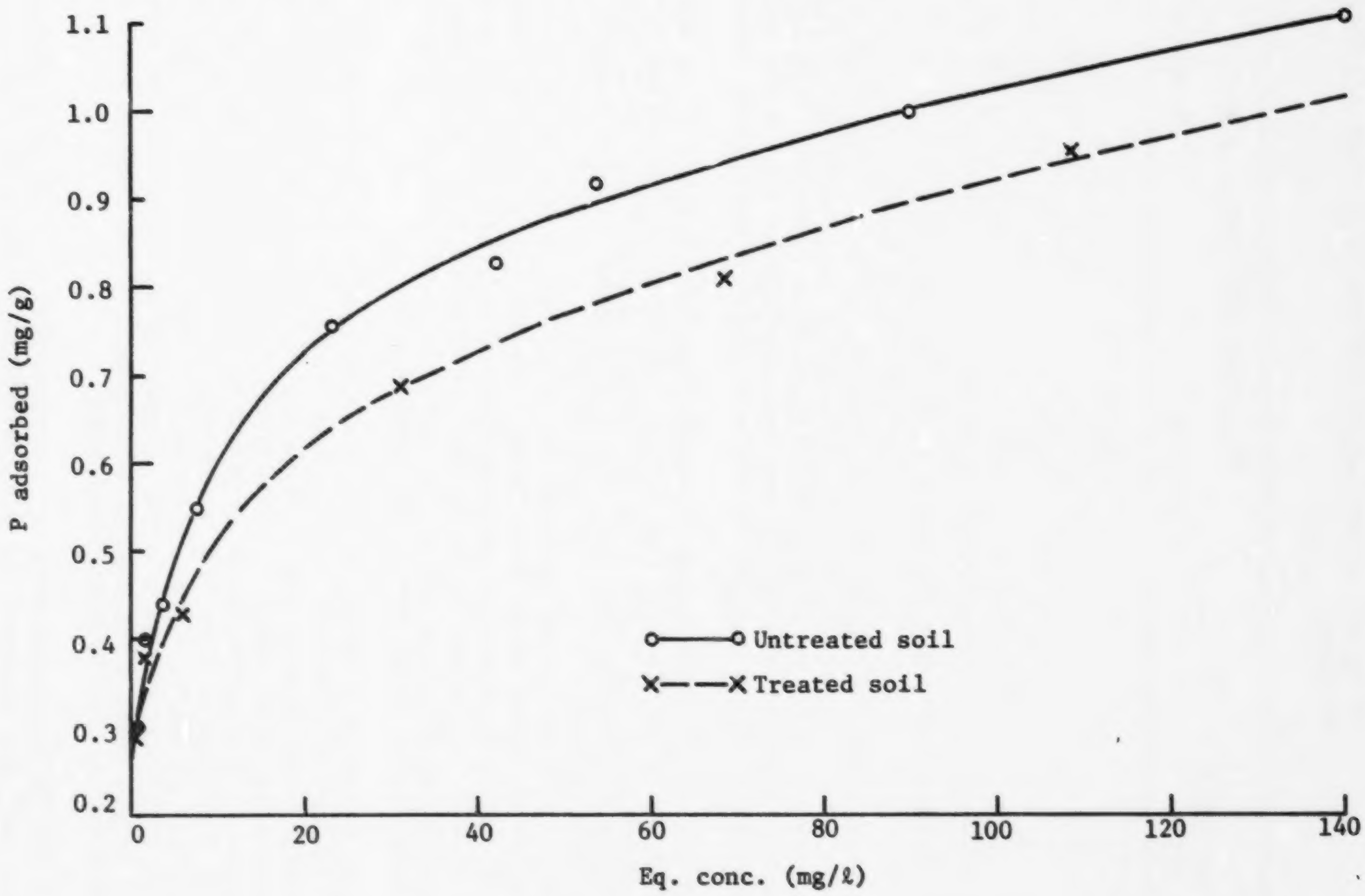

Figure 67. Phosphorus Adsorption Data for H_2O_2-Treated and Untreated Soil, 48-60 inches, Plotted According to the Freundlich Equation (8).

Table 113. Phosphorus Adsorbed at an Equilibrium Concentration of 100 mg P/l as Determined from the Freundlich Adsorption Isotherms.

Soil Depth feet	Phosphorus adsorbed - µg/g soil	
	Untreated	Treated[1]
1	510	590
2	990	810
3	1070	970
4	1060	920
5	1030	920

[1] Oxidized with H_2O_2 to remove organic matter.

matter increased slightly in adsorptive capacity when the organic matter was removed whereas the other layers which were low in organic matter decreased in adsorptive capacity after oxidation. The heating during oxidation and washing may have deactivated some of the adsorption sites or removed some of the more reactive sesquioxide hydrosols.

If one were to assume that a permissible concentration of leakage of phosphate from the five-foot profile should be an equilibrium concentration of 0.1 mg P per liter the amount of phosphorus which would be adsorbed in equilibrium with that concentration would be somewheres between 0.3 and 0.4 mg P per gram of soil. This would be equivalent in a 4,000,000 lb per acre-foot layer to 1200 to 1600 lb of P or the amount of P that would be added over a period of 6.6 to 8.8 years if 104 inches of wastewater were applied annually having a P content of 7.0 mg/l. In actuality in the reed canarygrass area the leakage concentration of 0.1 mg P/l in the second foot was attained after 553 lbs of P had been added over a four year period.

Bray Extractable Phosphorus. The concentration of phosphorus in the transient soil water moving through the profile has been shown to change abruptly with depth indicating that large quantities of phosphorus are being removed in the upper layers. In an attempt to evaluate this accumulation an extraction procedure was employed which was developed by Bray (74) to evaluate the so-called "available phosphorus" in soils. Table 114 gives the Bray extractable phosphorus at one foot intervals in a series of years on the corn rotation area and in single years after wastewater treatment on the reed canarygrass area and on the Hardwood forest area.

On the corn rotation area it is obvious that two inches of wastewater per week has increased the Bray phosphorus in the first foot

Table 114. Bray Phosphorus (μg/g) in Soil Samples Obtained in Different Years at Five Depths from Plots Receiving Various Levels of Wastewater Applications.

Plot Location and Soil Type	Soil Depth inches	1963			1965			1966		
		Wastewater - inches per week								
		0	1	2	0	1	2	0	1	2
Corn Rotation - Hublersburg clay loam	0-12	18.80	14.90	18.50	21.60	25.15	32.10	19.75	26.85	36.95
	12-24	3.15	2.05	1.00	1.80	3.20	2.35	2.20	1.80	4.25
	24-36	1.35	1.40	1.10	1.35	1.20	1.10	1.50	1.90	1.15
	36-48	1.25	0.90	1.10	1.35	0.70	0.70	1.45	1.20	0.90
	48-60	1.25	1.10	1.32	0.45	0.20	0.10	0.90	1.15	1.05

		1967			1968			1969			
		Wastewater - inches per week									
		0	1	2	0	1	2	0	1	2	2[1]
	0-12	28.50	25.50	41.65	33.30	31.60	60.35	21.75	32.40	50.65	29.80
	12-24	1.90	1.90	0.95	4.70	2.50	6.40	4.40	3.15	2.90	2.70
	24-36	2.20	0.65	0.80	2.65	1.60	2.65	3.75	0.90	1.35	3.40
	36-48	2.35	1.25	0.75	1.40	2.20	1.10	1.40	1.20	1.05	0.65
	48-60	0.75	1.20	1.35	1.35	1.25	0.85	1.35	2.25	2.35	1.05

		1967	
Gameland - Hardwood		Wastewater - inches/week	
		0	2
Morrison sandy loam	0-12	39.15	61.65
	12-24	7.75	11.10
	24-36	3.75	3.50
	36-48	3.35	2.40
	48-60	2.80	1.45

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[1] Reed canarygrass area - Hublersburg clay loam

substantially since 1963. The increase in the 1-inch per week area has been only half as great. The control (0-inch per week) area which has received phosphorus each year through additions of commercial fertilizer has shown only a slight increase over the six years. Going into the second foot and deeper the differences are small and erratic indicating that even though phosphorus is getting into the second foot of soil it has not yet accumulated sufficiently to be detected by the Bray test.

Even in the 2-inch per week reed canarygrass area which has received more than twice as much phosphorus as the 2-inch corn rotation area, an increase in Bray phosphorus in the second foot was not detectable.

In sharp contrast to these two sites on the fine textured Hublersburg soil, the Bray phosphorus in the second foot of the sandy Morrison soil was substantially greater than in the control but in the next three feet there was no detectable difference in the Bray phosphorus. So even on this site with a sandy loam soil an average annual application of 104 inches of wastewater, which began in Nov, 1965, has not resulted in a detectable change in available phosphorus in the third foot. It should also be pointed out that on this site no phosphorus was being removed in a harvested crop and hence had to recycle through the soil.

Boron Relationships

Previous Work. Because of the potential hazard to vegetation from boron concentrations above 1 mg/1 and the potential health hazard to humans of protracted intake of boron at higher concentrations the U.S. Public Health Service has recommended a limit of 1 mg/1 for drinking water. In the light of this criteria a more detailed study of the boron relationships was undertaken by Jardine (55). His review of the literature indicates that boron toxicity conditions have been observed with sensitive and semi-tolerant crops in irrigated areas of the semi-arid and arid western regions of the United States when irrigation waters contained as little as 0.5 parts per million (ppm) of boron in the irrigation water, particularly if conditions were such that evaporational concentration occurred in the root zone. In one instance in California (75), prolonged use of water with 0.4 ppm boron injured the foliage of lemon trees. The effects of boron were less severe in areas where annual rainfall exceeded 10 inches.

In humid regions boron deficiency is more prevalent than boron toxicity, particularly in the sandy soils which are low in organic matter. In the Eastern U.S. fertilizers are specifically formulated with as much as 1% borax for high boron demanding crops such as alfalfa, red beets, cabbage and cauliflower.

The chemistry of boron in soils is complex (75). Much of the boron available to growing crops is associated with the organic matter in the soil (76, 77). Boiling water extractable boron has been highly correlated with available boron and is commonly used as an estimate of the need for adding boron to satisfy the nutritional needs of a growing crop (78). When water soluble boron is added to soils much of it becomes adsorbed. Biggar and Fireman (79) showed that soils not only vary in their capacity to fix boron but also in the energy with which they retain it. They found that the Langmuir adsorption equation described the adsorption of boron up to concentrations ranging from six to 26 milligrams of boron per liter with various soils. The fixation of boron by soils has been found to be highly pH dependent over the range from pH 5.5 to pH 9.0, with solubility decreasing as pH increased. Hatcher et al. (57) attributed increases in amounts of boron adsorbed after liming acid soils to the exchangeable aluminum that precipitates as $Al(OH)_3$ at the higher pH. They found that for a wide variety of soils having pH values in the range 6.3 to 8.3 the amount of boron adsorbed from a 10 ppm boron solution was highly correlated with the product of the surface area of the soil and its citrate-extractable aluminum. Sims and Bingham (80) found that hydroxy aluminum compounds adsorbed ten times as much boron as hydroxy iron compounds.

The boron study in the Penn State Waste Water Project involved three phases: 1. A field study of the growth of a boron sensitive crop, snap beans, on the 0, 1 and 2-inch per week wastewater treatment sections of the corn rotation area; 2. A greenhouse study to evaluate the influence of previous wastewater treatment of a soil on the response of a boron sensitive crop, snap beans; and 3. An adsorption study to determine the effect of previous wastewater treatment on the boron fixing power of soil from three depths and the relation of dithionate-citrate extractable iron to this fixing power.

Field Experiment. In the field experiment, Tekoa green snap beans (*Phaseolis vulgaris* L.) were planted June 15, 1967 in four rows spaced three feet apart and 52 feet long in a mid-slope position on the 0, 1 and 2-inch wastewater plots. On Aug 28 plants were harvested from four 20-foot strips of rows from the two center rows and the total green weight determined. A subsample consisting of several plants from each 20-foot row sample was weighed green then separated into pods, leaves and stems and weighed green. The separate parts were then dried at 145°F, weighed, and ground in a Wiley mill.

A one gram sample of the dried, ground plant tissue was ashed at 485°C for eight hours then dissolved in a lithium chloride-HCl buffer solution and analyzed for P, K, Ca, Mg, Mn, Fe, Cu, B, Al, Zn and Na on an arc emission spectrograph (81). The yields of total bean plants is shown in Table 115. Yields of the separate parts were in the same order as the total plant. The data indicate that although the smallest yield was in the 2-inch treatment area it was not significantly smaller than in the control area (0-inch). The smaller yield was ascribed to more severe slug damage which occurred in the wetter plot.

The boron content of the plant parts and the weighted content in the whole plant are also shown in Table 115. Significantly greater ($P = 0.01$) boron content was found in the leaves as wastewater application increased. Boron content of the stems was not significantly different and only with the 2-inch treatment was boron content of the beans significantly greater than in the control. On a weighted total plant basis the boron content of the 1-inch treatment was not significantly greater than the control but boron content of the whole plant on the 2-inch treatment area was significantly greater ($P = 0.01$) than in the 0 or 1-inch treatment. The boron contents are not abnormally high and there was no evidence of boron toxicity on the foliage in the field.

The precipitation during the growth period was below normal in June but above normal in both July and August and hence not conducive to concentrating boron in the soil. Average concentration of boron in the applied wastewater in 1967 was 0.41 mg/l. During the irrigation period, April 19 - Oct 25, 1967 the soil water samples obtained with the suction lysimeters were as shown in Table 116. That boron is washed out is shown by the suction lysimeter values in Table 116 after irrigation

Table 115. Mean Yield and Boron Content of Beans Grown in Field Plots Receiving Various Levels of Wastewater. 1967 (55)

	Wastewater Level - inches per week		
	0	1	2
	Yield - lb per 20-foot row		
Fresh weight	18.3ab[1]	21.9b	14.4a
Dry weight	2.52ab	3.14b	1.98a
	Boron content - μg/g		
Leaves	16.75a	20.25b	25.50c
Beans	20.25a	22.50ab	25.50b
Stems	14.75a	14.75a	18.75a
Whole plant	18.08a	20.36a	24.22b

[1] Values in the same row without a common letter are significantly different at P = 0.01 using Duncan's multiple range test.

Table 116. Average Concentration of Boron (mg/l) in Lysimeter Samples During Irrigation (adsorption) and Non-irrigation (desorption) Periods, 1967-1968

	Wastewater Treatment Area - in./wk.					
Lysimeter Depth inches	0		1		2	
	A[1]	B[2]	A	B	A	B
6	0.06	0.03	0.25	0.10	0.34	0.12
24	0.04	0.02	0.10	0.05	0.20	0.11
48	0.03	0.03	0.07	0.04	0.13	0.09

[1] Irrigation period - 4/19/67 - 10/25/67

[2] Non-irrigation period - 10/26/67 - 4/18/68

ceased in the period Oct 26, 1967 - April 18, 1968. Boron concentration during the desorption period was decreased 50 to 60%. In regions where precipitation exceeds potential evapotranspiration it is probable that at present levels of boron in treated municipal wastewater it is unlikely that boron would become a health hazard in drinking water or a phytotoxic hazard to any, except the most boron sensitive, crop. However, since some segments of the detergent industry have been encouraging the use of borax as a laundry aid and this might result in larger inputs of boron in municipal wastewaters a greenhouse experiment was carried out to determine what level of boron in an applied solution might result in phyto-toxicity over a short haul period.

Greenhouse Experiment. Bulk soil samples were obtained from the three wastewater treatment plots from successive one foot zones to a depth of three feet. The samples were air dried and crushed to pass a sieve with one-fourth inch openings. Ten pounds of soil was weighed into each of 120 one gallon plastic pots with holes in the bottom for drainage. The pots were arranged in a greenhouse bench in a triple lattice design, including a buffer row of six pots at each end of the triple lattice arrangement. The experiment included 36 treatments in triplicate, involving a factorial of four boron treatments with nine different soil materials. The latter included soil from three depths in three wastewater treatment areas. The boron treatments involved solutions containing 0.0, 0.5, 5.0 and 10.0 milligrams of boron per liter.

Nitrogen, phosphorus, potassium, calcium and magnesium were added as soluble salts in solution to provide the equivalent of 100#(pounds) N, 65# P, 83# K, 142# Ca and 70# Mg per two million pounds of soil.

Boron solutions were added in one inch increments (590 ml per pot). Each one inch application was equivalent to 0.00, 0.13, 1.30 or 2.60 pounds of boron per two million pounds of soil.

The test plant was the Tekoa green snap bean which had been used in the field experiment. Two seeds were planted in each pot and later thinned to one plant per pot. Weekly observations were made on plant height, leaf color, leaf distortions and other symptoms.

After five applications of the boron solutions at approximately weekly intervals, differences in boron toxicity had become strongly expressed and boron irrigations were stopped. Beginning on April 2, six weeks after planting, irrigation was with distilled water. The plants were harvested in the ninth week. All leaves which had fallen from the plant prematurely were saved and weighed with the green plants, then oven-dried, weighed again and ground in a Wiley mill. One gram samples or the total sample, if less than one gram, were ashed and handled for chemical analyses as were the field experiment samples.

Soil samples (150 to 200 grams) were taken from each pot to full depth of the pot using a soil sampling tube. Moist subsamples were used for measuring pH and for extraction of water-soluble manganese (1:10 soil: water ratio by weight). An air-dried subsample was used for determination of autoclave-extractable boron which has been found by Lobnik and Baker (Unpublished research at Penn State) to give results not significantly different from the hot-water extraction method. In the autoclave procedure 10 grams of dry soil is placed in a 100 ml heat resistant plastic bottle. Twenty milliliters of distilled water and 0.5 ml of 100% barium chloride solution are added. After covering the bottles with aluminum foil they are autoclaved for 40 minutes at 21 pounds per square inch steam pressure (110°C). Pressure is reduced during the last five minutes of autoclaving. After removing from the autoclave and cooling slightly the supernatant liquid is poured off into a centrifuge tube and clarified by centrifugation. A two ml aliquot of the clear supernatant is pipetted into a polypropylene test tube and boron determined by the Carmine Red procedure (82).

The first observation of stress occurring in the bean plants was in the fourth week after planting. Some of the plants growing in soil from the second and third foot began to show interveinal chlorosis. Since this was not a typical boron toxicity symptom and was not related to the boron treatments it was finally diagnosed as a manganese toxicity. The data in Tables 117 through 119 corroborated this diagnosis by the high concentration of Mn in plants which showed the interveinal chlorosis.

The severe boron toxicity symptoms of marginal necrosis and yellowing of the older leaves and cupping downward of all of the leaves occurred with all soil sources with the 10 mg B treatment. The same symptoms occurred with the 5.0 mg B treatment but to a lesser degree. None of the 0.0 or the 0.5 mg B treatments showed boron toxicity symptoms but did show manganese toxicity symptoms in soils from the second and third foots.

Because of the interaction of the manganese and boron toxicities the effect of boron treatment on yield (Table 120) was significant only with the upper foot of soil in which manganese toxicity did not occur. Only the 5.0 and 10.0 mg B per liter treatments had significantly poorer growth than the 0.0 boron treatment. The field wastewater treatment area from which the soil materials were derived was only erratically related to the boron treatment effect.

Water soluble Mn was strongly inversely related to pH of the soil (Table 121) and directly related to Mn content of the plants.

Boron content of the plants, Table 122, was significantly increased ($P = 0.01$) by boron treatment particularly with soil from the 2nd and 3rd foots. Previous wastewater treatment which increased the autoclave extractable boron in the upper foot of the soil (Table 123) did not have a significant effect on boron content of the plants. Depth from which the soil was taken also did not have a significant effect on boron content of the plant even though the autoclave extractable boron content of the first foot was significantly greater ($P = 0.01$) than both the 2nd and 3rd foot (Table 123).

Table 117. Average Plant Weights and Chemical Composition of Bean Plants from Greenhouse Experiment--Control Area Soil (55)

Soil* material	Boron treatment conc'n mg/1	Plant weight grams	Plant tissue content										
			%				µg/g						
			P	Ca	Mg	K	Mn	Fe	Cu	B	Al	Zn	Na
0 - 1'													
	0.0	6.01	0.23	2.82	0.39	1.79	39	73	7	46	40	45	10
	0.5	5.60	0.21	2.76	0.35	1.53	43	210	6	24	51	40	10
	5.0	4.71	0.21	2.82	0.33	1.65	49	35	3	143††	29	38	12
	10.0	3.21	0.18	2.20	0.33	1.75	103	200	9	285††	25	29	5
0 - 2'													
	0.0	2.03	0.11	1.84	0.40	1.80	231†	51	5	72	38	62	16
	0.5	2.93	0.12	1.74	0.34	1.69	140†	111	4	46	31	67	16
	5.0	1.61	0.11	1.64	0.39	1.87	268†	55	5	100††	74	98	21
	10.0	1.37	0.13	1.78	0.36	2.14	175†	84	6	345††	39	43	15
2 - 3'													
	0.0	1.50	0.11	1.38	0.50	2.04	214†	129	6	21	295	69	14
	0.5	1.69	0.15	2.33	0.55	1.93	216†	81	7	136	51	52	27
	5.0	1.41	0.13	1.60	0.53	2.06	230†	229	10	99††	59	78	23
	10.0	0.85	0.13	1.42	0.42	1.66	124†	43	3	222††	32	52	17

*Bulk samples of soil material were obtained from these depths for greenhouse study.
†Manganese toxicity occurred.
††Boron toxicity occurred.

Table 118. Average Plant Weights and Chemical Composition of Bean Plants from Greenhouse Experiment--One Inch Area Soil (55)

Soil* material	Boron treatment conc'n mg/1	Plant weight grams	Plant tissue content										
			%				µg/g						
			P	Ca	Mg	K	Mn	Fe	Cu	B	Al	Zn	Na
0 - 1'													
	0.0	4.19	0.23	2.38	0.47	1.85	29	63	6	23	41	53	33
	0.5	4.79	0.23	2.51	0.42	1.90	28	60	7	27	37	41	10
	5.0	4.62	0.18	2.22	0.44	1.47	111	32	5	64	30	40	15
	10.0	4.61	0.24	2.46	0.50	1.75	47	61	7	193	25	59	11
1 - 2'													
	0.0	0.80	0.14	1.54	0.34	1.32	101†	88	5	18	45	41	28
	0.5	0.27	0.10	1.04	0.37	1.20	194†	297	8	24	49	55	18
	5.0	0.36	0.14	1.56	0.38	1.80	163†	103	8	129††	51	65	12
	10.0	0.56	0.10	1.05	0.39	1.32	207†	176	8	275††	47	76	20
2 - 3'													
	0.0	0.48	0.07	0.92	0.38	1.53	126†	102	5	95	260	71	28
	0.5	0.60	0.09	0.85	0.39	1.29	184†	73	6	26	109	62	14
	5.0	0.53	0.10	0.52	0.30	1.28	75†	155	8	109††	63	60	28
	10.0	0.31	0.11	0.54	0.32	1.25	118†	149	9	205††	188	60	3

*Bulk samples of soil material were obtained from these depths for greenhouse study.
†Manganese toxicity occurred.
††Boron toxicity occurred.

Table 119. Average Plant Weights and Chemical Composition of Bean Plants from Greenhouse Experiment--Two Inch Area Soil (55)

Soil* material	Boron treatment conc'n mg/1	Plant weight grams	Plant tissue content										
			%				µg/g						
			P	Ca	Mg	K	Mn	Fe	Cu	B	Al	Zn	Na
0 - 1'													
	0.0	6.35	0.19	2.30	0.52	2.08	177	63	5	172	26	66	13
	0.5	5.79	0.25	2.28	0.54	1.68	43	64	6	37	25	47	12
	5.0	5.40	0.21	2.35	0.46	1.92	84	64	5	113††	30	53	11
	10.0	4.74	0.27	2.48	0.40	1.96	46	70	7	295††	19	52	13
1 - 2'													
	0.0	1.19	0.13	2.20	0.48	2.25	373†	96	7	33	101	59	32
	0.5	0.95	0.14	1.99	0.43	1.87	221†	52	5	77	38	46	15
	5.0	1.47	0.13	2.07	0.49	2.21	453†	90	7	209††	65	110	24
	10.0	1.29	0.11	1.88	0.42	2.36	323†	81	6	307††	47	92	21
2 - 3'													
	0.0	0.51	0.07	0.86	0.41	1.35	245†	90	6	19	85	56	16
	0.5	1.03	0.08	1.06	0.48	1.82	431†	308	5	30	229	100	47
	5.0	0.51	0.11	1.71	0.53	1.94	346†	80	7	163††	81	101	20
	10.0	0.46	0.10	0.88	0.46	1.69	470†	64	6	332††	78	80	27

*Bulk samples of soil material were obtained from these depths for the greenhouse study.
†Manganese toxicity occurred.
††Boron toxicity occurred.

Table 120. Effect of Boron Treatment and Source of Soil on Dry Weight (grams) of Bean Plants in Greenhouse Experiment (55)

	Boron treatment				
	Solution concentration--mg/l				
	0.0	0.5	5.0	10.0	
	Total boron added--µg/g of soil				
	0.000	0.323	3.230	6.460	
Effluent Area	Soil Depth: 0 - 1 foot				
0"	6.09	5.74	4.75	3.25	4.96a[1]
1"	4.27	4.83	4.68	4.63	4.60a
2"	6.41	5.84	5.44	4.77	5.62b
Ave.	5.59c	5.47bc	4.96b	4.22a	5.06c
Effluent Area	Soil Depth: 1 - 2 feet				
0"	2.09	2.99	1.66	1.43	2.04c
1"	0.88	0.36	0.42	0.58	0.56a
2"	1.27	1.05	1.50	1.40	1.30b
Ave.	1.41a	1.47a	1.20a	1.14a	1.30b
Effluent Area	Soil Depth: 2 - 3 feet				
0"	1.56	1.72	1.45	0.89	1.40b
1"	0.50	0.64	0.59	0.36	0.52a
2"	0.56	1.07	0.54	0.55	0.68a
Ave.	0.87a	1.14a	0.86a	0.60a	0.87a
Ave. (all values)	2.62a	2.69a	2.34a	1.98a	

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[1] Values in the same row or column without a common letter are significantly different, P = 0.01, using Duncan's multiple range test.

Table 121. pH and Water Soluble Manganese Content of Soil from Pots Used in Greenhouse Study. (55)

Soil depth	pH	Water soluble Mn µg/g
	Control area	
0 - 1'	5.6	0.269
1 - 2'	5.0	0.524
2 - 3'	4.8	0.817
	1" effluent/week soil area	
0 - 1'	5.8	0.222
1 - 2'	4.8	0.525
2 - 3'	4.7	0.503
	2" effluent/week soil area	
0 - 1'	5.8	0.099
1 - 2'	5.2	1.738
2 - 3'	4.8	3.451

Table 122. Effect of Boron Treatment and Source of Soil on Boron Content (μg/g) of Bean Plants in Greenhouse Experiment (55)

Soil material source	Boron treatment mg/1				
	0.0	0.5	5.0	10.0	Ave.
Effluent Area		Soil Depth: 0 - 1 foot			
0"	46.7	24.0	143.3	285.5	124.4b[1/]
1"	22.7	26.7	63.7	193.3	76.6a
2"	171.7	37.0	113.0	295.0	154.2b
Ave.	80.3a	29.2a	106.7a	257.8b	118.4a
Effluent Area		Soil Depth: 1 - 2 feet			
0"	72.3	46.3	100.0	345.3	141.0a
1"	18.0	24.3	129.0	275.0	111.6a
2"	33.3	78.7	208.7	307.0	156.9a
Ave.	41.2a	49.8a	145.9b	309.1c	136.5a
Effluent Area		Soil Depth: 2 - 3 feet			
0"	21.7	136.3	99.3	222.0	119.8a
1"	94.7	26.0	109.0	205.0	108.7a
2"	19.3	30.0	163.0	332.0	136.2a
Ave.	45.2a	64.1a	123.8a	253.1b	121.6a
Average (All values)	55.6a	47.7a	125.4a	273.3b	

[1/] Values in the same row or column without a common letter are significantly different at P = 0.01 using Duncan's multiple range test

Table 123. Autoclave-Extractable Boron Content of Soil Materials Used in Greenhouse Experiment--μg/g (55)

Soil material source Depth feet	Effluent Level - inches/week 0.0	1.0	2.0
0 - 1	0.063a[1/]	0.178b	0.215b
1 - 2	0.000a	0.002a	0.023a
2 - 3	0.000a	0.000a	0.000a
Ave.	0.021a	0.059b	0.079c

Depth feet	Effluent Level - inches/week 0.0	1.0	2.0	Ave.
0 - 1	0.063b[2/]	0.178b	0.215b	0.151b
1 - 2	0.000a	0.002a	0.023a	0.008a
2 - 3	0.000a	0.000a	0.000a	0.000a

[1/] Values in the same row without a common letter are significantly different, P = 0.01, using Duncan's multiple range test.

[2/] Values in the same column without a common letter are significantly different, P = 0.01, using Duncan's multiple range test.

Adsorption Experiment. In the boron adsorption study, each of the nine soil materials were equilibrated with seven concentrations of boron, 0.5, 1.0, 2.0, 5.0, 10.0, 25.0 and 50.0 mg/1. Ten gram samples of each soil were weighed out in 50 milliliter polypropylene centrifuge tubes. Twenty milliliters of the boron solutions were added, the tubes stoppered and then shaken in a mechanical shaker for twelve hours. The samples were then centrifuged 5 minutes at 2000 rpm in an International No. 2 centrifuge. An aliquot of the clear supernatant was analyzed for boron by the Carmine Red Method.

Plots of Langmuir adsorption isotherms indicated a bi-modal adsorption pattern with breaks in the curves occurring at equilibrium concentrations ranging from 4 mg./1. to 20 mg./1. Biggar and Fireman (79) found similar deviations in their Langmuir plots at concentrations ranging from six to 26 mg. B per liter.

The boron adsorbed by the nine soil materials equilibrated with the 5.0 mg B/1. solution typifies the differences between the soil materials, Table 124. Although the control soils would have been expected to have the largest adsorptive capacity, since that area had not been receiving the boron, such was not the case. Instead the 1-inch treatment area had the largest adsorptive capacity. However the 2-inch treatment area which had been receiving the largest amounts of boron in the applied wastewater did have the least adsorptive capacity when averaged over all three depths. In seeking a possible explanation for this anomalous situation, the soils were extracted with dithionate-citrate solution to determine the relative quantities of free iron oxide since Hatcher et al (57) had shown that sesquioxides were very important in fixing boron. Table 125 indicates that B adsorbed from the 5.0 mg B per liter solution was strongly correlated with the extractable Fe_2O_3. The 1-inch wastewater treatment area which had the highest average boron adsorptive capacity also had the largest content of extractable Fe_2O_3. This appears to be a reasonable explanation of its anomalously high boron adsorptive capacity.

Table 124. Boron Adsorbed by the Soil Materials Equilibrated with the 5.0 mg/1 Solution (55)

	Boron adsorbed--μg/g			
	Effluent level inches/week			
Soil depth	0	1	2	Ave.
0 - 1'	1.06	4.06	1.50	2.22a[1/]
1 - 2'	2.54	5.74	1.90	3.38b
2 - 3'	4.30	5.96	2.36	4.22c
Ave.	2.64b	5.26c	1.92a	

[1/] Values in the same row or column without a common letter are significantly different, P = 0.01 using Duncan's multiple range test.

Table 125. Dithionate-Citrate Extractable Fe_2O_3 and Boron Adsorptive Capacity of the Nine Soil Materials from the Three Wastewater Treatments. (55)

Soil Depth	Wastewater Level	Extractable Fe_2O_3	Boron Adsorbed[1]
	in./week	%	mg B/kg soil
0 - 1'	0	0.83	1.06
0 - 1'	2	1.07	1.50
1 - 2'	0	1.25	2.54
1 - 2'	2	1.43	1.90
2 - 3'	2	1.54	2.36
2 - 3'	0	1.68	4.30
0 - 1'	1	2.13	4.06
1 - 2'	1	2.37	5.74
2 - 3'	1	2.39	5.96

[1] From the 5.0 mg B per liter solution.

Oxygen Relationships

Previous Work. Treated sewage effluent was applied to agronomic cropland to achieve renovation and to increase the recharge of the ground water reservoir. Amounts applied were 0, 1.0 and 2.0 inches at weekly intervals for approximately 25 consecutive weeks.

When such large amounts of effluent are applied to a soil, some changes in the natural soil environment can be expected. Of great concern is the nature of the change in the aeration status of the soil. Pore space containing the gaseous phase is filled to a large extent by the liquid phase and thereby could alter the interchange of gases between the atmosphere and the soil as well as within the soil itself.

Aerobic conditions must prevail in the upper soil zone to maintain proper root function and desirable organic matter transformations. Since treated sewage effluent is relatively high in nitrogen it is not inconceivable that possible pollution of the ground water reservoir could result if conditions were favorable for nitrification. To prevent this, it would be desirable to stimulate denitrification in the deeper layers of the soil and thereby convert the excess nitrate to molecular nitrogen and minimize the reduction of iron and manganese, or permit their subsequent reoxidation in a cyclic system.

Lemon and Erickson (86a) in characterizing soil aeration with the platinum microelectrode noted that oxygen concentration at the root surface should increase as soil water tension increases because as water contents diminish, additional pore space is available for gaseous oxygen diffusion (86).

The critical oxygen diffusion rate (O.D.R.) of soils in which roots of many plants will not grow does not appear to be sharply defined. Stolzy and Letey (83) reported that an O.D.R. value of 20×10^{-8}g$\cdot$cm$^{-2}\cdot$min^{-1} appeared to be critical for the root growth of many plants. However, Van Diest (84) found no yield differences in top growth of corn due to differences in soil O.D.R. values ranging from a low of 10×10^{-8}g cm^{-2} min^{-1} on compacted soil to a high of 50×10^{-8}g$\cdot$cm$^{-2}\cdot$min^{-1} on well aerated soil.

Cannon (85) in working with 30 plant species noted that when oxygen was entirely absent from the soil in which the roots were growing, growth ceased in all species. The oxygen concentration for normal growth was temperature dependent, being higher in higher temperatures. Wiegand and Lemon (86) calculated a critical oxygen concentration in the liquid film at the root surface of onion root segments to be 4.45×10^{-6}g cm^{-3}. This is equivalent to 12% oxygen in the gaseous phase and they suggested that this is a conservative estimate of the critical oxygen concentration for other roots.

Many changes take place in a soil when it is subjected to continual wetting. Not only are oxygen concentrations diminished but also the appearance of reduced forms of nitrogen, iron and manganese becomes important.

Although the effects of moisture on denitrification are not clearly understood, Allison *et al.* (87) and Jones (88) concluded that the effect of moisture *in soils* is primarily one of reducing the volume of air filled pores with a consequent reduction in oxygen concentration. Miller and Johnson (89) and Patrick and Wyatt (90) both demonstrated large losses of nitrogen when soils were subjected to low tensions or submergence.

When soils are waterlogged and the partial pressure of oxygen declines, manganese is reduced to the more soluble manganous form. Piper (91) showed that waterlogging a soil for a week had about the same effect on the yield and manganese content of the plants as did the application of manganese sulfate at a rate of 5 cwt per acre. The increase in soluble manganese brought about by waterlogging has also been reported by Godden and Grimmett (92) who showed that plants grown in undrained pots were very much richer in manganese than those grown in drained pots.

The behavior of iron in the soil is similar to that of manganese. Should anaerobic conditions prevail, the amount of the reduced form of iron rapidly increases. Godden and Grimmett (92) pointed out that under conditions favorable to soil aeration and leaching, the total amount of soluble iron in the soil at any one time is small. Similar results were reported by Islam and Elahi (93) who found that the amount of ferrous iron gradually increased and remained practically constant after about three weeks of waterlogging.

Site Description and Procedures. The experimental area consisted of 18 acres in a 2 year rotation of hay and corn. Experimental locations were in a contour strip arrangement. The study sites were in pairs with respect to application rates but individual with respect to crop times application rate. Laterals running from the main irrigation line were 80 feet apart. The sprinklers were spaced at 80 foot intervals along the laterals in a triangular network.

Within each experimental site, measurement of oxygen diffusion and oxygen concentration were recorded at five different depths, 3, 6, 12, 18 and 24 inches. Installations at each depth included ten platinum microelectrodes, 3 oxygen concentration chambers, a thermistor for recording soil temperature and a tensiometer or Bouyoucos moisture block for determining soil moisture content. Two porous cup suction lysimeters placed at 6 and 24 inches were installed for the collection of water samples. A size No. 10 can was placed at each location to record the amount of effluent that had been applied and to obtain a composite sample of the effluent.

The oxygen diffusion apparatus used was similar to that described by Van Doren and Erickson (Mimeo report: Technique for measuring the rate of oxygen diffusion through the soil with the platinum microelectrode. 1958. Dept of Soils, Michigan State Univ, Lansing, Mich) and was obtained from Dick's Machine and Tool Co, Lansing, Mich. The platinum microelectrodes were 22 gauge and the potential applied was -0.65 volts. The diffusion current in microamperes was converted to O.D.R. values ($gO_2 \times 10^{-8}\ cm^{-2}\ sec^{-1}$) by multiplying by 5.93. The microelectrodes of various lengths are shown in Figure 68.

Because it proved difficult to continually reinsert 22 gauge wire up to depths of 24 inches without badly damaging the electrodes, all electrodes were permanently placed. Initial random insertion of the microelectrodes was carried out by first driving a steel rod, whose diameter was slightly larger than that of the insulated portion of the electrode, to within 1 inch of the desired depth. The electrode was then placed in the pre-made channel and pushed the remaining inch into new soil, insuring a good seal. The soil was then tamped around the protruding electrode lead wire.

At the close of the investigation, electrodes at the 3 and 6 inch level at six locations were pulled and cleaned with 0000 steel wool (the abrasive action polishes the platinum surface, removing any poisonous substances), and reinserted in the same vicinity. After 5 minutes, to insure steady state conditions a new measurement was made. The two mean values at each location at each depth were compared to determine if poisoning was a problem. In only one of the twelve cases were the means significantly different and indicative that "poisoning" had occurred. It was therefore assumed that leaving the microelectrodes in place over a four-week period was an acceptable technique.

The oxygen concentration apparatus consisted of an oxygen sensor, (YSI Model 52) and a recycling mechanism consisting of two hypodermic needles (intake and exhaust) and a rubber bulb to circulate the gases from the diffusion chamber, inserted in the soil, through the oxygen sensor. The meter readout values of percent oxygen were corrected on the basis of known volumes of the analyzer and chamber to give actual percent oxygen in the chamber alone.

The oxygen diffusion chambers were made from aluminum tubing of various diameters cut to desired lengths. The bottom of the chamber was closed by a disc of aluminum window screening. The upper end was closed with a rubber stopper through which protruded a short section of ½ inch copper tubing topped by a rubber septum. Each chamber was brought to a constant internal gaseous volume of 200 ml by including various amounts of solid glass rods within the chamber. The chambers used at the several depths are shown in Fig. 68.

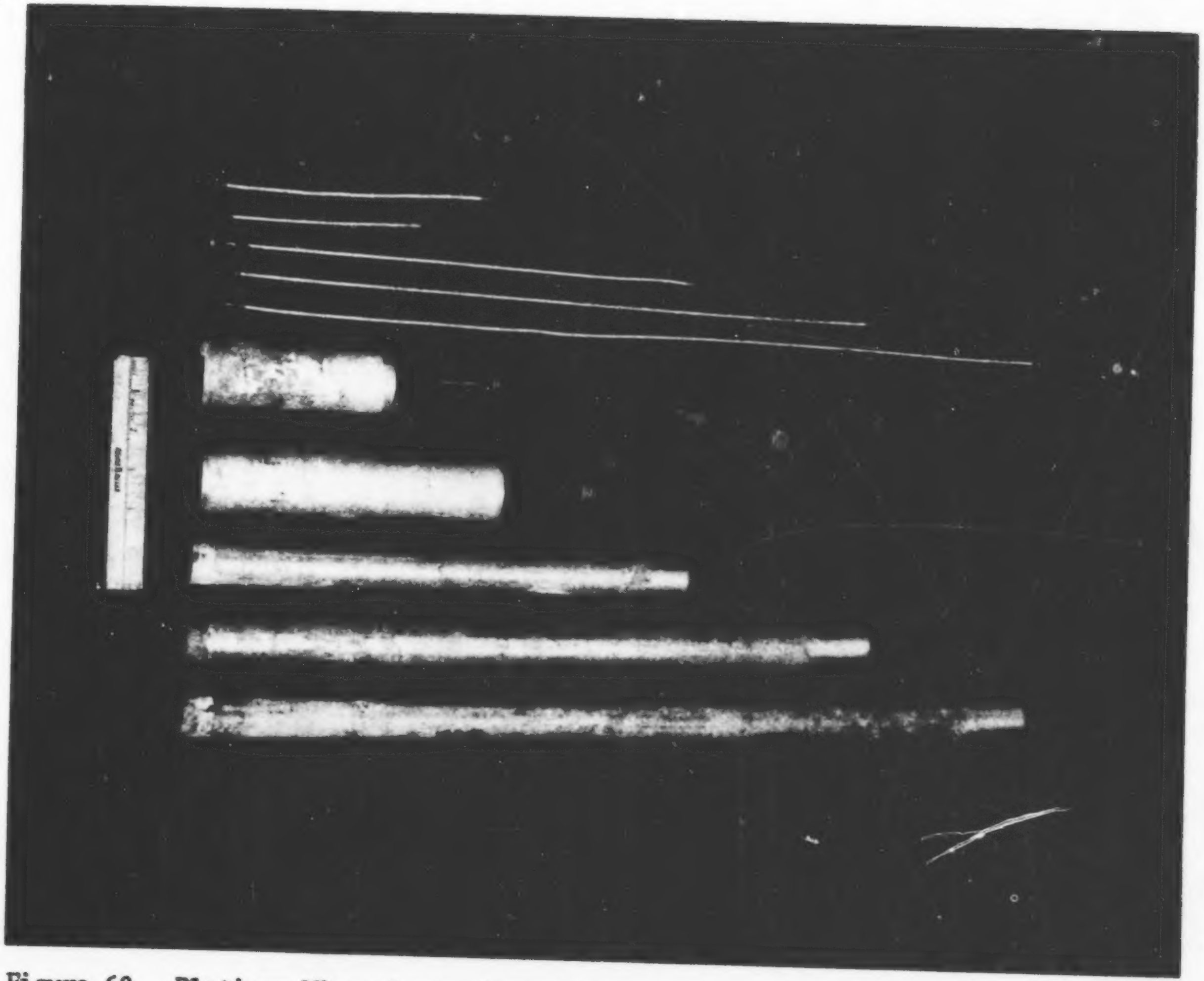

Figure 68. Platinum Microelectrodes and Oxygen Concentration Chambers.

Chamber placement was achieved by first drilling a hole with a portable power auger to the desired depth. The chamber was then pushed into place. The voids between the chamber and the hole were filled with silica flour to insure a tight fit, and clay soil material was used to make a firm seal at the surface.

A series of determinations of physical soil properties relevant to this investigation were made by using soil cores. These cores were collected with a Uhland core sampler. Soil samples were obtained at the 3, 6, 12, 18 and 24 inch levels. Samples were subjected to tensions of 50, 100, 200, 400, 800 and 1000 cm of water on a pressure plate apparatus. Total pore space was determined from the dry bulk density. Water filled capillary pore space and aeration pore space was determined for each tension. A separate soil sample at each depth was secured and used to calibrate the Bouyoucos moisture blocks.

To keep the concentration of nitrogen, iron and manganese under constant surveillance, soil water samples were taken and analyzed on a weekly basis throughout the course of the experiment.

Installation of the porous cup suction lysimeters was much like that of the oxygen chambers. The lysimeter was inserted in a pre-drilled hole after a layer of silica flour had been placed at the bottom to insure good contact with the porous cup. To minimize leakage along the plastic tubing to the porous cup, silica flour was poured around the outside of the tubing and the soil at the surface was mounded and tamped against the protruding tubing. The lysimeters were evacuated to an internal pressure of approximately 1/3 atmosphere prior to irrigation by using a vacuum pump. When irrigation ceased the internal vacuum was relieved and the soil water removed from the lysimeter chamber by a suction siphon arrangement. In the control area an attempt was made to obtain samples after each rain but in most cases the soil water tension was so great that only one-third as many samples were obtained as in the effluent treated areas.

Nitrogen analyses included the quantitative determination of NH_4^+-N, NO_3^--N and NO_2^--N. Ammoniacal nitrogen was analyzed according to a modification of the Nessler procedure (94). Nitrate nitrogen determinations were made using brucine as described in the Standard Methods for the Examination of Water and Waste Water (20). Nitrite nitrogen was determined using 1-naphthylamine . HCl (20). The total amounts of iron and manganese were determined as follows. A 50 ml water sample was evaporated to dryness at 150°C, the residue dissolved in 0.1N HCl, and then analyzed with a Perkin-Elmer Atomic Adsorption Spectrophotometer.

The crops occupying the land in this experiment were hay and corn (*Zea mays*). Originally alfalfa (*Medicago sativa*) was planted, but after two years, the stand in the 1 and 2 inch treatment areas became largely crowded out by timothy (Phleum pratense), quackgrass (Agropyron repens), and a variety of weeds. However, there was still a good stand of alfalfa in the control area. The corn location consisted of two varieties, one for silage (Pa 602A) and the other for grain (Pa 444). The silage variety occupied approximately one-third of the contour strip and was planted in 19 inch rows. The remaining two-thirds of the strip containing the grain variety was divided into equal widths of 19 and 38 inch row spacings. The experimental sites were located in the 38 inch row spacing area.

All statistical analysis was carried out on the IBM-7074 computer and the Duncan's multiple range test was used to define significance of the differences between variables.

Oxygen Diffusion Rates (O.D.R.). The analysis of variance for the O.D.R. data showed that the only main factors that proved to be significant, were crop and depth of sampling. The only interaction of importance, which proved significant, was "irrigation treatment" versus "day after cessation of irrigation". The nature of this interaction being that "day-3" O.D.R. values were significantly larger than "day-1" values on the irrigated sites but not on the control site.

Although O.D.R. decreased with an increase in the amount of applied irrigation, the difference was not significant (Table 126).

Soil moisture data taken at the time of each weekly sampling showed that the control area generally contained less water on a volume basis than did the effluent areas. The 1.0 and 2.0 inch effluent treatment areas were usually above or near field capacity at all depths while the control areas were only at or above field capacity at the 24 inch depth.

Oxygen diffusion rates were significantly higher in the corn areas than in the hay areas. The difference between the two locations was due largely to the higher O.D.R. in the upper 3 inches of the soil. The loosening action of tillage in the corn locations was reflected in a higher average total and aeration pore space.

Differences in O.D.R. among the time factors (succeeding weeks or days after cessation of irrigation) were not significant. During the test period, soil moisture contents did not change appreciably from week to week or from day-1 to day-3 after cessation of irrigation. With almost constant soil moisture contents, O.D.R. would not be expected to change significantly.

The O.D.R. values at the 3 and 6 inch depths differed significantly from the 12, 18 and 24 inch depths. The differences in O.D.R. appear to be associated with differences in aeration porosity of core samples taken at the various depths.

Table 126. Ranked Means in Ascending Order of the Main Factors of Oxygen Diffusion Rate Experiment.*

Factors	Level	O.D.R. x 10^8g cm^{-2} min^{-1} Mean
Effluent Treatment (in.)	2.0	19.5a
	1.0	19.6a
	0.0	22.9a
Crop	Hay	18.6a
	Corn	22.7b
Weeks	1	19.7a
	4	20.6a
	2	20.9a
	3	21.4a
Depth (in.)	18.0	14.7a
	12.0	17.3a
	24.0	17.9a
	3.0	26.6b
	6.0	26.8b
Day	1	19.6a
	3	21.8a

* The values followed by the same letter are not significantly different by the Duncan's multiple range test at the 5% level.

At a tension of 800 cm of water, the average aeration pore space in the 3 and 6 inch zones was 15%, that in the 12, 18 and 24 inch zones was only 13%. At 50 cm tension, the respective aeration pore space values were 10% and 8% in the upper and lower zones.

Oxygen Concentration. The extent to which soil air differs in oxygen concentration from atmospheric air, is determined by the rate at which it is replenished by diffusion. Soil water content is also important because it affects diffusion.

The data in Table 127 indicate that all three effluent treatments were significantly different from each other with oxygen concentration decreasing as effluent treatment increased. The range in concentration of oxygen was relatively narrow, 19.6% to 18.4%, and even the smallest mean would generally not be regarded as indicative of adverse aeration conditions.

Table 127. Ranked Means of the Main Factors of the Oxygen Concentration Experiment.

Factor	Level	Percent Oxygen Mean
Treatment (in.)	2.0	18.4a
	1.0	19.0b
	0.0	19.6c
Crop	Corn	18.8a
	Hay	19.2a
Depth (in.)	3.0	18.4a
	6.0	18.6a
	24.0	19.2b
	12.0	19.2b
	18.0	19.4b
Week	8	18.1a
	4	18.4a
	2	18.6a
	6	18.8a
	5	19.3a
	3	19.5a
	7	19.5a
	1	19.6a

[1] The values followed by the same letter are not significantly different by the Duncan's multiple range test at the 5% level.

Oxygen concentrations did not differ significantly between the two crop locations or with time over the eight-week period but did differ significantly with depth.

The depth effects were in some respects unorthodox in that oxygen concentrations in the upper two zones were significantly smaller than in the lower three zones. As a possible explanation one can assume a diffusion system in which a normal vertical concentration gradient (source gradient) would exist in the vertical aeration pore continuum which in turn is imbedded in a vertical oxygen sink gradient, namely, the microbial and root sinks. The gradient in the vertical aeration pore continuum could be relatively small but the sink gradient could change very abruptly. As a result of the interaction of the two gradients and the displacement of the vertical pore continuum by the diffusion chamber it is conceivable that the oxygen concentration distribution by depth shown in Table 127 could eventuate.

Nitrogen, Manganese and Iron Concentrations. The data in Table 128 indicate that significant differences occurred as a result of effluent treatment with respect to the nitrogen forms but not with respect to the manganese or iron. The significant differences in the concentration of nitrate, nitrite and ammoniacal nitrogen were due to the 2.0 inch level weekly application of effluent. Differences between the control and 1.0 inch level of effluent treatment were not significant.

Table 128. Concentration of Various Forms of Nitrogen and of Manganese and Iron in Soil Water Samples.*

Factor	Level	NO_3^- Nitrate	NO_2^- Nitrite	NH_4^+	Mn	Fe
Effluent Treatment (in.)	0.0	1.0a	0.017a	0.35a	0.07a	0.09a
	1.0	2.4a	0.030a	0.40a	0.05a	0.05a
	2.0	6.1b	0.056b	1.28b	0.06a	0.07a
Crop	Corn	4.2b	0.024a	0.67a	0.04a	0.07a
	Hay	3.2a	0.052b	0.82a	0.07b	0.05a
Depth (in.)	6.0	3.0a	0.042a	0.81a	0.03a	0.08a
	24.0	4.4b	0.035a	0.68a	0.08b	0.06a

* Within any factor grouping mean values followed by the same letter are not significantly different by the Duncan's multiple range test at the 5% level.

With respect to crop locations, nitrate was significantly higher under corn and nitrite concentration was significantly higher under hay. Crop location differences were not significant with respect to ammoniacal nitrogen.

The significantly higher nitrate levels under corn were primarily a reflection of the higher nitrate levels under corn in the control and 1.0 inch effluent treatments. The significant crop x effluent treatment interaction is evident in Table 129.

The significantly higher nitrite level under hay was primarily due to the higher nitrite levels under hay on the two effluent treated areas.

Table 129. The Crop x Effluent Interaction[1] with Respect to Nitrate Nitrogen Levels in Suction Lysimeter Samples Averaged Over Both Depths

	Effluent Treatments - in. per week		
	0	1.0	2.0
Crop	Nitrate nitrogen - mg per liter		
Hay	0.2	1.1	6.7
Corn	1.9	3.8	5.6

[1] Interaction significant at P = 0.01

The crop x effluent treatment interaction in this case was significant at the 5% level. It is pertinent to recall that the O.D.R. values under hay were significantly lower than under corn and may have contributed to a greater persistence of the nitrite which was being applied in the effluent or to a greater production of nitrite.

The significantly higher manganese levels under hay was primarily due to the higher manganese levels at the 24 inch depth under hay. The crop x depth interaction was significant at the 1% level. Again, as in the case of the nitrite, the significantly lower O.D.R. under hay may have contributed to greater persistence of the more soluble reduced form of manganese.

Effects of depth of sampling were significant with respect to nitrate and manganese but not with respect to iron, nitrite or ammoniacal nitrogen.

Mean concentrations of nitrate, nitrite, and ammoniacal nitrogen and of manganese and iron in the applied sewage effluent during June, July and August were 4.6, 0.20, 19.2, 0.14, and 0.16, respectively. In comparing these values with the mean values in the soil water samples it is apparent that passage of the effluent through the soil-crop system substantially diminished the sum concentration of the nitrogenous components and the manganese and iron.

O.D.R. and oxygen concentration data and the nitrite, manganese, and iron values in the soil water samples indicate that aerobiosis is being maintained in the upper 24 inches, hence denitrification cannot be regarded as contributing substantially to nitrogen removal. Soil analyses indicate no significant accumulation of ammoniacal nitrogen in the effluent treated areas therefore it can be assumed that the NH_4-N is being removed by the crop and soil microbes directly and/or

SECTION VII

FORESTED AREAS

Soil Percolate Water Quality

Samples of percolating water were collected at various soil depths in the forested areas during the period 1963 to 1969. Only results of the 1969 analyses are discussed here, however, all data collected during the earlier years are shown in Tables A-23 to A-42 in the Appendix. The chemical composition of the sewage effluent applied to the Farm Woodlot Site in 1969 is shown in Table 130. Weekly variations in concentration of constituents are shown by the range between maximum and minimum values. Total amounts of each constituent applied at the 2-inch per week rate are also shown in Table 130. The fertilizer value of the effluent is readily evident in that the 2-inch application provided commercial fertilizer constituents equivalent to approximately 271 pounds of nitrogen, 151 pounds of phosphate, (P_2O_5), and 210 pounds of potash (K_2O). This would be about equal to applying 2000 pounds of a 13-8-10 fertilizer.

The average concentrations of constituents in the percolate samples for various soil depths on the irrigated and control plots at the Farm Woodlot Site are shown in Tables 131 and 132. The average composition of water samples obtained at various depths indicated that after 7 years of operation, during which approximately 34 feet of wastewater had been applied in the 2-inch per week treatments, the renovation capacity of the biosystems was still satisfactory, except in the 2-inch red pine area where nitrate concentrations were above desirable levels.

The first stage of renovation in the forested areas occurs during passage of the effluent through the forest floor. Concentrations of MBAS (detergent residual) were reduced by approximately 55 percent. MBAS analyses were not made where small volumes of percolate were obtained because previous results indicated a consistently high degree of renovation. For instance, results in 1968 indicated that percolation through the upper 4 feet of soil decreased average concentrations by 78 to 81 percent. These data indicate that the relatively thin and highly permeable forest floor layer has a high adsorptive capacity and biological degradation capacity for the detergent residue. It should also be noted that the methylene blue process used to determine the MBAS concentration indicates only the apparent concentration since both organic and inorganic anions commonly found in soils give positive errors in the analysis. This is evident in the results of the analysis of percolate collected from the control plots, which indicated an average apparent MBAS concentration ranging from 0.12 to 0.17 mg/l (Table 132). Since the concentrations of MBAS in percolating water leaving the forest floor are only in the magnitude of approximately 0.17 mg/l, the percent renovation may actually be considerably higher than that indicated.

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Table 130. Chemical Composition of Sewage Effluent Applied on the Experimental Plots (Farm Woodlot Site) During the Period April 15, 1969 to October 29, 1969.

Constituent	Range Min	 Max	Ave	Total amount applied[2]
	mg/l	mg/l	mg/l	lb/acre
pH	7.1	8.3	7.8	-
MBAS[1]	0.1	1.2	0.4	5
Nitrate-N	0.0	12.5	5.4	70
Organic-N	0.0	16.5	6.4	82
NH_4-N	0.0	32.5	9.5	123
Phosphorus	0.821	17.143	4.606	66
Potassium	6.7	20.8	13.5	175
Calcium	18.2	34.0	28.0	363
Magnesium	9.4	17.7	14.3	185
Sodium	22.5	59.5	38.1	494
Chloride	8.7	68.7	43.2	560
Boron	0.2	0.4	0.3	4
Manganese	0.0	0.2	0.1	1.3

[1] Methylene blue active substance (detergent residue).

[2] Amount applied on plots which received 2 inches of effluent per week.

Results in Table 131 also indicate that the "living filter" was highly efficient in removing phosphorus, one of the principal nutrients responsible for eutrophication. Phosphorus concentrations at the 2-foot soil depth were reduced by 97 to 99 percent. Phosphorus concentrations of percolating water samples taken from deep groundwater wells indicated that phosphorus concentrations of percolating water at the 4-foot depth on the control plots ranged from 0.05 to 0.07 mg/l. These values are not very different from the irrigated plots considering that 34 feet of sewage effluent with phosphorus concentrations ranging from 6 to 10 mg/l have been applied to the plots over a 7-year period. Phosphorus concentrations have increased in the treated areas, particularly at the 6-inch depth. As shown in Tables 130 and 131 the average concentrations in the treated areas ranged from 0.056 to 0.261 mg/l, whereas, in the control areas the average concentrations only ranged from 0.020 to 0.051 mg/l. Phosphorus concentrations in percolating water have fluctuated at any one depth from year to year but the general trend is for the average concentration to diminish with depth (Figures 69, 70, 71, and 72.

Table 131. Average Concentration of Constituents in the Percolate Water Samples Collected from Tension Lysimeters in the Effluent Treated Plots at the Farm Woodlot Site During the Irrigation Period April 15 to October 29, 1969.

Plot and soil depth	No. of samples	Weekly application	pH	MBAS	NO_3-N	Org-N	NH_4-N	Cl	P	Na	K	Ca	Mg	Mn	B
			Concentration in mg/liter												
Effluent Quality	27		7.8	0.38	5.4	6.4	9.5	43.2	4.060	38.1	13.5	28.0	14.3	0.08	0.28
Hardwood		1													
F.F. 2/	28		7.1	0.13	11.6	2.6	3.3	29.0	3.913	21.5	14.3	24.3	9.5	0.19	0.21
6 inches	10		7.7	1/	6.8	0.9	1.1	36.3	0.212	37.4	5.7	30.6	24.8	0.03	0.31
24 inches	5		7.6	1/	4.9	1.2	0.9	89.2	0.065	59.5	8.2	27.9	21.7	0.05	0.37
48 inches	15		7.9	0.09	7.2	1.0	1.1	36.0	0.047	51.1	5.8	33.9	28.4	0.03	0.04
Red Pine3/		1													
F.F.	23		7.1	0.16	11.7	4.6	3.8	31.7	3.537	24.6	14.0	22.5	9.2	0.14	0.19
6 inches	19		7.5	1/	17.6	1.0	1.1	31.6	0.056	32.9	10.9	33.4	27.2	0.04	0.21
12 inches	16		7.7	1/	14.4	0.7	1.2	24.7	0.129	27.9	9.3	49.8	24.7	0.03	0.20
24 inches	5		7.7	1/	9.0	0.7	0.5	25.6	0.068	1/	1/	1/	1/	1/	1/
48 inches	7		7.9	1/	4.2	1.1	0.6	55.6	0.064	48.2	5.5	35.3	26.6	0.03	0.06
Red Pine3/		2													
F.F.	16		7.3	0.22	10.0	4.6	5.6	48.4	4.352	41.7	21.4	27.9	13.4	0.42	0.24
6 inches	14		7.5	1/	10.5	2.1	1.5	21.7	0.261	21.1	11.9	34.9	17.0	0.06	0.29
12 inches	5		6.9	1/	12.7	1.1	0.5	27.8	0.111	37.6	8.2	17.5	6.9	0.18	0.32
24 inches	9		6.9	1/	19.6	1.0	1.1	34.3	0.040	41.7	3.7	15.9	6.2	0.06	0.20
48 inches	11		6.4	1/	24.2	0.3	0.9	61.8	0.037	41.1	2.1	5.3	2.8	0.21	0.10

Table 131. Continued.

Plot and soil depth	No. of samples	Weekly application	pH	MBAS	NO_3-N	Org-N	NH_4-N	Cl	P	Na	K	Ca	Mg	Mn	B
							Concentration in mg/liter								
Old Field		2													
6 inches	11		7.4	[1]	7.3	2.4	1.2	31.9	0.293	33.7	3.3	20.9	12.6	0.03	0.24
12 inches	21		7.7	0.03	2.8	1.0	0.8	25.2	0.057	38.4	3.4	35.2	20.6	0.03	0.25
24 inches	5		7.6	[1]	8.3	2.1	1.5	24.5	0.122	42.9	5.3	29.8	18.6	0.04	0.28
48 inches	11		7.7	[1]	2.3	1.3	0.9	28.0	0.098	49.6	5.7	21.2	17.7	0.07	0.21

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[1] Not determined.

[2] Forest Floor (1.5 to 2.0 inches thick).

[3] Irrigated with rotating sprinklers on 42-ft risers, 1963-1967 and on 5-ft risers thereafter.

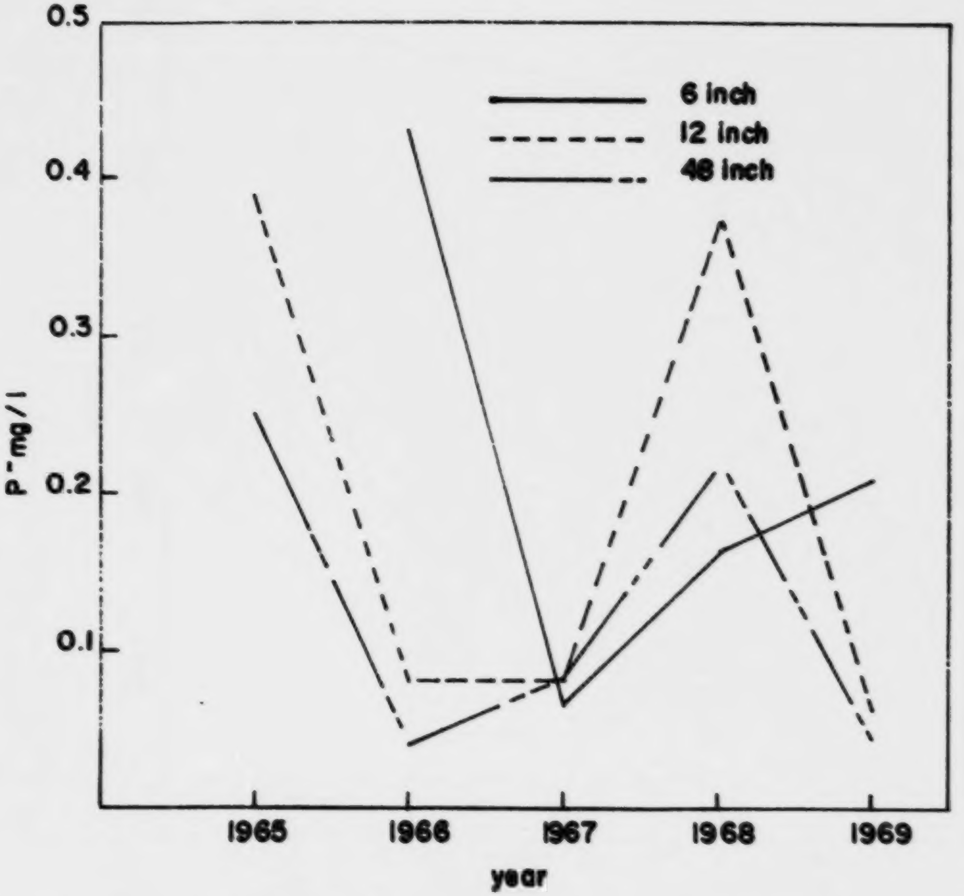

Figure 69. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths in the Hardwood Area on Hublersburg Soil Which Received One Inch of Wastewater at Weekly Intervals. 1965-1969

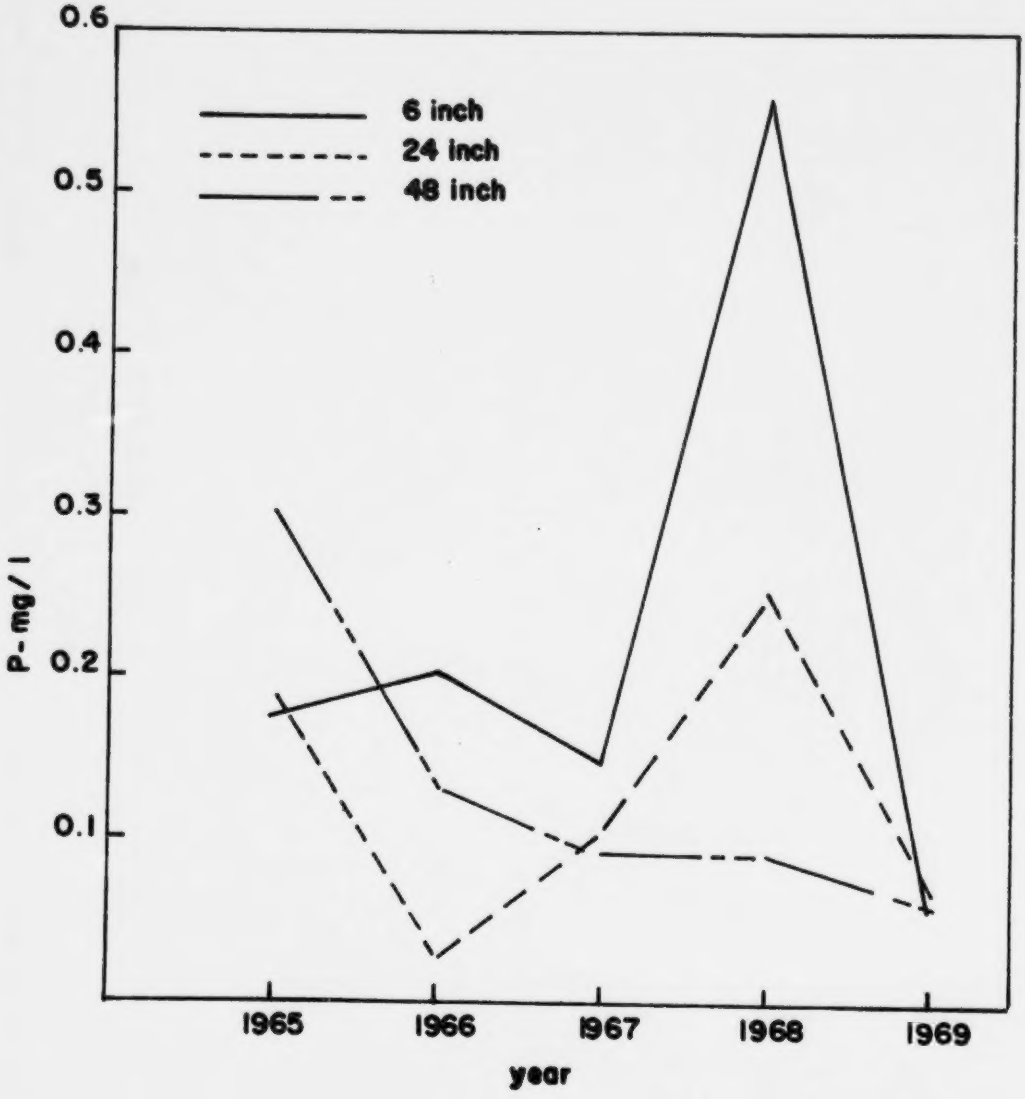

Figure 70. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths in the Red Pine Area on Hublersburg Soil Which Received One Inch of Wastewater at Weekly Intervals. 1965-1969

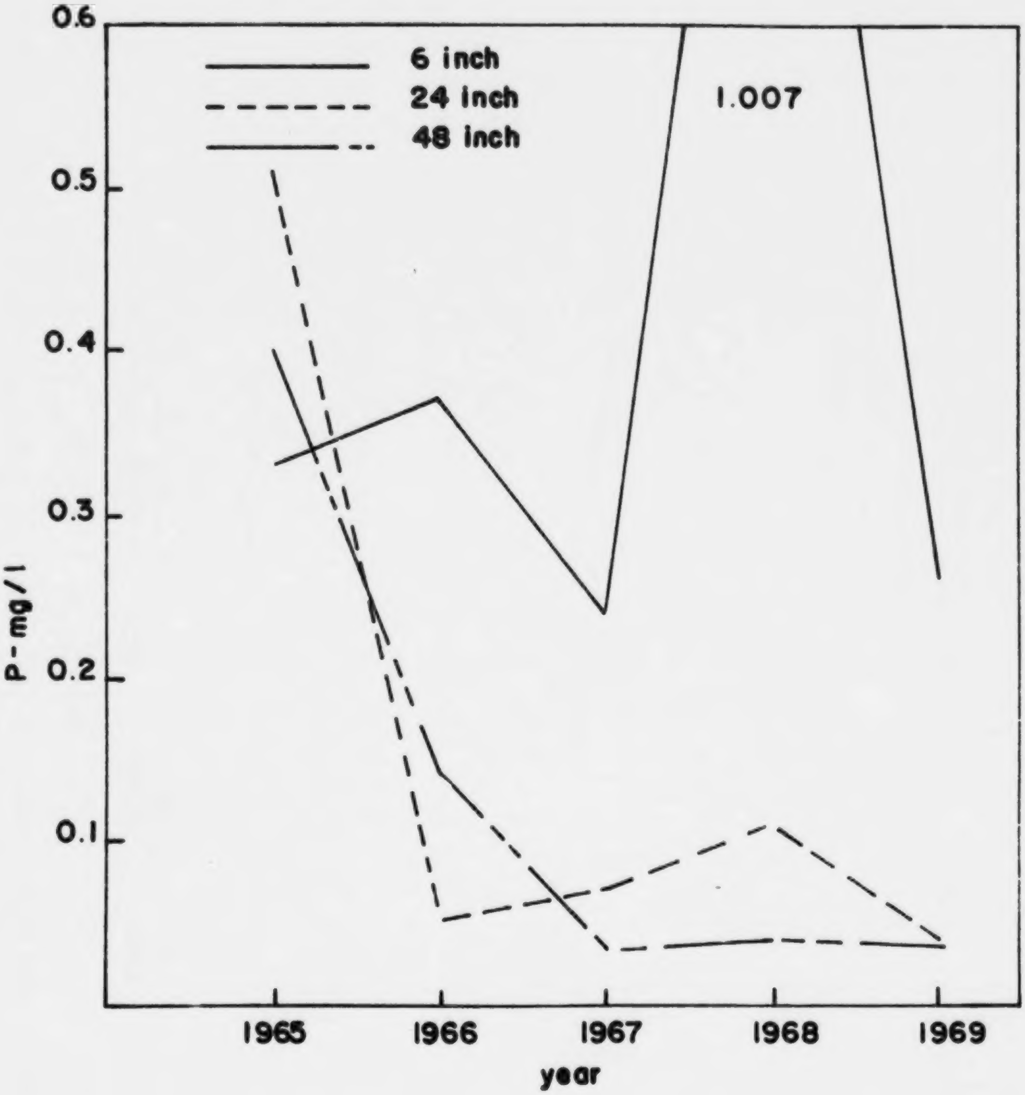

Figure 71. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths in the Red Pine Area on Hublersburg Soil Which Received Two Inches of Wastewater at Weekly Intervals. 1965-1969

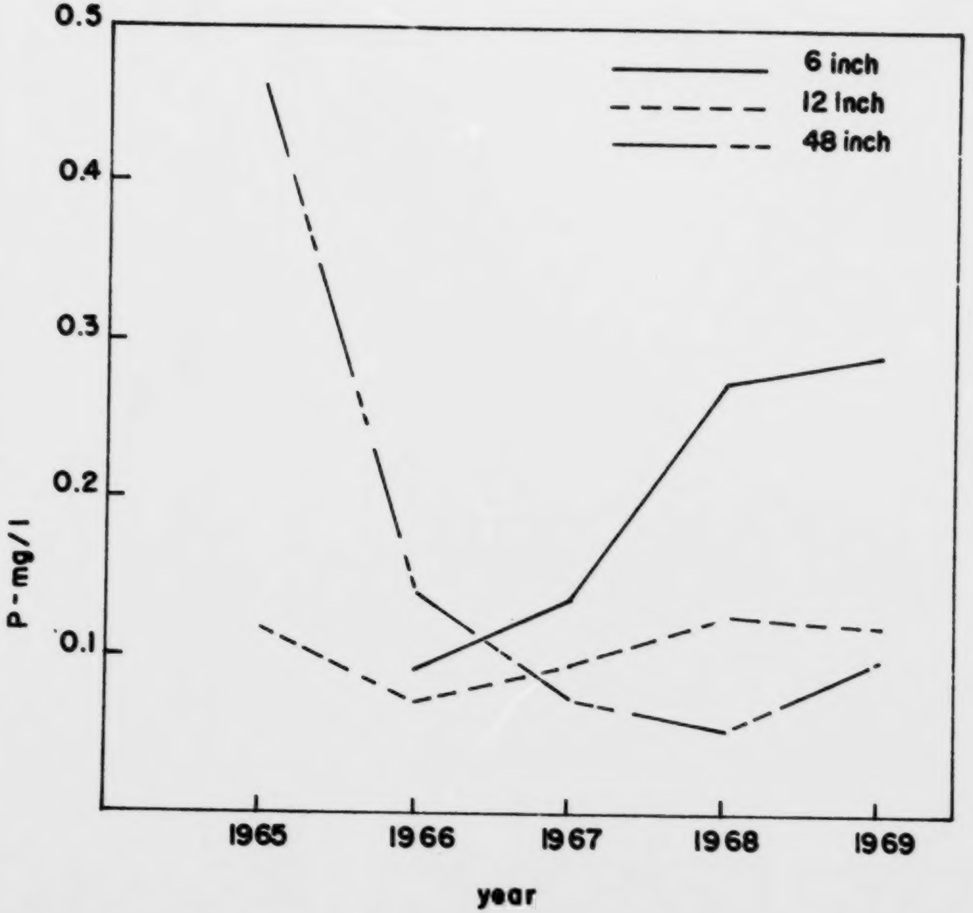

Figure 72. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths in the Old Field Area on Hublersburg Soil Which Received Two Inches of Wastewater at Weekly Intervals. 1965-1969

Nitrogen, like phosphorus, is one of the elements responsible for eutrophication and the profuse growth of aquatic plants in streams. After 7 years, nitrate-nitrogen concentrations in percolating water at the 4-foot soil depth ranged from 2.3 to 24.2 mg/1 (Table 131) and, except for the red pine, 2-inch plot, were below the U.S. Public Health Service recommended drinking water limit of 10 mg/1. Concentrations of nitrate-nitrogen in percolating water at the 4-foot depth on the control plots ranged from 0.1 to 0.5 mg/1. Nitrate-nitrogen concentration of the groundwater as measured at deep wells on the site remained below 3 mg/1.

Increasing concentrations of nitrate-nitrogen in the forested areas receiving continued irrigation with sewage effluent could become a major problem and a deterrent to long-term use of forested areas for disposal sites. One possible way to reduce the nitrate concentration is through denitrification, a microbiological process that occurs when biodegradable organic material and nitrates are combined under anaerobic conditions. Certain bacteria use the oxygen of nitrates in their metabolism, thereby reducing the nitrates to nitrogen and nitrogen oxides, which escape to the atmosphere. To create conditions favorable for biodenitrification, drainage periods between irrigation should be long enough to allow aeration in the upper soil horizons. When nitrates and biodegradable organic material reach the deeper soil horizons denitrification should occur if denitrifying organisms are present and anaerobic conditions exist.

The average concentrations of Na, K, Ca, Mg, Mn and B were increased or decreased in variable amounts in the upper soil horizons. Average concentrations of manganese were quite similar on irrigated and control plots (Tables 131 and 132). Whereas, average concentrations of boron, potassium, calcium, sodium, magnesium and chloride were considerably higher on the irrigated plots. They may cause a slight increase in total salinity but the groundwater would still easily meet drinking water quality standards.

In addition to the red pine plots which were initially irrigated with rotating sprinklers over the canopy on 42-foot risers a second area (designated as New Red Pine) was irrigated with sprinklers under the canopy on 5-foot risers. Irrigation of this plot was initiated in July 1964. Results for 1965 to 1968 are given in Tables A-35 and A-36 in the Appendix. Results for 1969 for this area are presented in Table 133. Although this area has only been treated during 6 years rather than 7 years there appears to be no large differences in terms of renovation of the wastewater between the two methods of application. In terms of efficiency in operation and maintenance, the shorter risers are more desirable.

Another mixed hardwood, 3 acre plot designated as New Gamelands Area was established in November, 1965 and has received an application of

Table 132. Average Concentration of Constituents in the Percolate Water Samples Collected from Tension Lysimeters in the Control Plots at the Farm Woodlot Site During the Period April 15 to October 29, 1969.

Plot and soil depth	No. of samples	Weekly application	pH	MBAS	NO_3-N	Org-N	NH_4-N	Cl	P	Na	K	Ca	Mg	Mn	B
			Concentration in mg/liter												
Hardwood		1													
F.F.2/	16		6.6	0.17	3.9	3.6	2.1	0.4	0.347	0.4	9.5	14.1	1.4	0.10	0.08
6 inches	12		7.7	1/	0.4	1.7	0.6	1.8	0.023	1.3	0.6	15.5	9.5	0.04	0.03
12 inches	6		7.7	0.02	0.4	2.0	1.5	1.3	0.082	1.5	6.1	31.1	21.1	0.04	0.06
24 inches	12		7.3	0.04	0.3	1.1	1.6	2.4	0.025	2.3	3.6	13.2	10.1	0.18	0.05
48 inches	7		6.6	1/	0.1	1.8	0.6	1.6	0.072	3.6	1.2	4.8	3.3	0.04	0.03
Red Pine		1													
F.F.	16		6.5	0.12	6.7	3.2	2.4	0.6	0.338	0.5	8.9	17.4	1.7	0.10	0.06
6 inches	6		7.8	1/	0.1	1.1	0.3	1.0	0.020	1.1	2.5	31.4	19.6	0.03	0.04
12 inches	7		7.8	1/	0.1	1.0	0.4	0.4	0.037	1.1	0.5	41.2	20.4	0.04	0.03
24 inches	4		7.9	1/	0.2	1.1	0.4	0.8	0.040	2.7	2.2	33.7	21.9	0.06	0.05
48 inches	1		7.6	1/	0.2	1.4	0.4	0.9	0.010	1/	1/	1/	1/	1/	1/
Red Pine															
F.F.	16		6.5	0.12	6.7	3.2	2.4	0.6	0.338	0.5	8.9	17.4	1.7	0.10	0.06
6 inches	6		7.8	1/	0.6	1.6	0.9	6.6	0.051	6.9	12.2	45.6	26.9	0.04	0.12
12 inches	9		7.7	1/	0.3	0.7	0.7	7.9	0.047	4.9	4.3	55.7	17.8	0.02	0.06
24 inches	6		7.7	1/	0.1	0.9	0.4	19.7	0.034	11.8	4.7	30.9	14.7	0.03	0.05
48 inches	9		6.9	1/	0.5	0.6	0.4	15.3	0.050	10.9	1.8	3.2	0.7	0.08	0.03

Table 132. Continued.

Plot and soil depth	No. of samples	Weekly application	pH	MBAS	NO_3-N	Org-N	NH_4-N	Cl	P	Na	K	Ca	Mg	Mn	B
							Concentration in mg/liter								
Old Field		2													
6 inches	13		7.7	1/	0.4	2.6	1.0	0.3	0.036	1.5	2.6	37.4	21.9	0.02	0.05
12 inches	6		8.1	1/	0.2	2.6	0.9	0.3	0.099	1.5	7.6	51.4	27.1	0.03	0.08
24 inches	2		7.9	1/	0.4	1.4	0.7	0.2	0.288	1.0	0.4	39.6	18.8	0.08	0.05
48 inches	15		7.3	1/	0.2	0.8	0.6	0.4	0.051	1.9	1.8	2.7	0.8	0.05	0.03

1/ Not analyzed.

2/ Forest floor (1.5 to 2.0 inches thick).

Table 133. Average Concentration of Percolate Samples Collected from Forest Floor Pans and Tension Lysimeters in the New Red Pine 2" Per Week Area During the Irrigation Period 4-15-69 to 10-29-29.[2/]

	No. of samples	pH	MBAS	NO_3-N	Org-N	NH_4-N	Cl	P	Na	K	Ca	Mg	Mn	B
							Concentration in mg/1							
Effluent Quality	27	7.8	0.48	3.7	4.7	14.4	43.6	5.784	35.2	13.5	27.7	13.8	0.16	0.31
Forest Floor Pans	27	7.2	0.15	15.9	2.7	3.5	38.9	4.924	32.3	15.5	23.9	11.5	0.05	0.22
6 inches	26	7.5	0.11	22.6	0.8	1.8	34.3	1.700	32.2	13.3	44.1	27.1	0.03	0.26
12 inches	21	7.7	0.09	21.3	1.1	1.4	32.8	0.446	31.3	8.3	55.0	30.1	0.03	0.24
24 inches	25	7.7	[1/]	20.8	0.8	1.5	37.5	0.316	40.8	4.6	47.1	27.9	0.02	0.20
48 inches	22	7.1	0.10	17.7	1.0	0.8	33.7	0.250	31.8	5.2	14.7	10.4	0.11	0.16

[1/] Not analyzed.

[2/] Irrigated with rotating sprinklers on 5 ft risers.

2 inches of sewage effluent per week continuously throughout the year. Approximately 432 inches of effluent have been applied to the area as of December 31, 1969. The soil at this site is a Morrison sandy loam rather than Hublersburg clay loam.

The average concentration of constituents in the sewage effluent and in the percolate water samples collected at various soil depths during 1966 to 1968 are given in Tables A-37 to A-39 in the Appendix. Results for 1969 are given in Table 134. Average concentrations of constituents in natural percolating water on the control plots is given in Table 135.

It is quite apparent that at this year round application of wastewater the concentration of phosphorus was still being substantially decreased in 1969 from a mean annual value of 5.532 mg P/1 in the applied effluent to a value of 0.137 in the soil water at a depth of 48 inches. However average concentration of nitrate-nitrogen in the percolating water at the 4-foot soil depth was 23.7 mg/1. This is more than twice the recommended limit (10 mg/1) for potable water. In comparison, average nitrate-nitrogen concentration in the control area was only 0.3 mg/1 (Table 135).

A summary of the nitrate data for all the forested areas is given in Table 136 and shown graphically in Figure 73. It is clear that the forested areas can handle a 1-inch per week application without having the mean annual concentration of the 48-inch depth exceed the Public Health Service limit. However, when 2 inches were applied per week either in the April-Nov period with red pine on the Hublersburg soil or year-around with hardwoods on the Morrison soil the NO_3-N concentration at the 48-inch depth rapidly exceeded the Public Health Service limit. On the other hand, 2 inches of wastewater applied weekly on the old field area in the April-Nov period did not result in excessive NO_3-N values at the 48-inch depth.

The difference between the 2-inch red pine and 2-inch old field areas on the same soil type probably resides in the difference in the recycling of the nitrogen through the two vegetative covers. In the red pine relatively less nitrogen is assimilated in the annual growth than in the herbaceous annuals and perennials in the old field and larger amounts of readily decomposable organic residues are deposited annually in the old field. The larger quantities of carbonaceous material in the old field area may also promote a higher degree of denitrification in this fine textured soil. The sandiness of the soil on the 2-inch hardwood area would not be conducive to denitrification of the larger nitrogen load applied in a year-around irrigation period and the hardwood leaf litter although more decomposable than the red pine needle litter would not be as decomposable as the old field residues.

Table 134. Average Concentration in Percolate Samples Collected from Forest Floor Pans and Tension Lysimeters in the New Gamelands Area Which Received 2" of Effluent Per Week During the Period 1-1-69 to 12-31-69.

	No. of samples	pH	MBAS	NO_3-N	Org-N	NH_4-N	Cl	P	Na	K	Ca	Mg	Mn	B
							Concentration in mg/1							
Effluent Quality	30	7.6	0.41	4.4	8.1	13.8	44.5	5.532	31.7	12.4	29.9	13.6	0.10	0.27
Forest Floor Pans	33	7.4	0.22	10.1	4.3	8.7	40.4	4.890	31.8	14.1	28.1	12.8	0.26	0.23
6 inches	17	7.5	[1]	17.0	1.1	1.3	43.2	0.319	31.5	13.7	37.4	20.9	0.05	0.23
12 inches	22	7.6	0.12	18.5	2.2	1.8	41.3	0.415	34.7	12.6	43.6	29.3	0.03	0.24
24 inches	13	7.4	[1]	24.4	1.8	1.2	43.2	0.104	29.5	13.2	34.7	21.4	0.18	0.21
48 inches	14	7.2	0.07	23.7	1.4	1.4	49.1	0.137	39.8	17.6	38.9	22.3	0.38	0.24

[1] Not analyzed.

Table 135. Average Concentration in Percolate Samples Collected from Forest Floor Pans and Tension Lysimeters in the Control Plot at the New Gamelands Site During the Period 1-1-69 to 12-31-69.

	No. of samples	pH	MBAS	NO_3-N	Org-N	NH_4-N	Cl	P	Na	K	Ca	Mg	Mn	B
							Concentration in mg/1							
Forest Floor Pans	27	6.9	0.11	3.6	3.8	3.0	1.0	0.361	0.4	8.3	15.5	1.4	0.62	0.07
6 inches	11	7.0	0.07	0.4	2.9	1.6	2.6	0.031	1.5	4.6	22.4	11.5	1.21	0.04
12 inches	5	7.6	0.03	0.4	5.1	1.3	1.0	0.037	0.8	6.5	24.3	15.3	0.24	0.07
24 inches	4	7.3	1/	0.1	3.1	0.7	2.4	0.032	1.5	3.9	35.0	15.4	0.06	0.04
48 inches	9	6.9	0.02	0.3	1.2	0.5	2.1	0.059	1.9	3.7	5.8	3.9	0.06	0.04

1/ Not analyzed.

Table 136. Mean Annual Concentration (mg/1) of Nitrate-Nitrogen in Suction Lysimeter Samples at Three Depths in Forest Areas Receiving Various Levels of Wastewater. 1965-1969

Red Pine - Hublersburg Soil

Year	6-Inch Depth			24-Inch Depth			48-Inch Depth		
	inches per week			inches per week			inches per week		
	0	1	2	0	1	2	0	1	2
1965	0.2	1.7	9.2	--	0.4	10.7	0.9	2.2	3.9
1966	0.1	1.5	26.8	0.2	0.2	14.6	0.1	2.1	9.3
1967	0.9	6.9	9.6	0.4	5.1	10.6	0.9	1.7	13.8
1968	0.5	18.7	21.8	0.2	6.1	17.6	0.9	2.7	19.9
1969	0.1	17.6	10.5	0.2	9.0	19.6	0.2	4.2	24.2
Ave	0.4	9.3	15.6	0.3	4.2	14.6	0.6	2.6	14.0

Hardwood - Hublersburg Soil

Year	6-Inch Depth		24-Inch Depth		48-Inch Depth	
	inches per week		inches per week		inches per week	
	0	1	0	1	0	1
1965	0.1	1.0	--	0.2	--	0.0
1966	0.1	3.3	0.1	2.1	0.1	0.2
1967	0.4	13.3	0.4	5.4	0.3	1.4
1968	0.4	10.9	0.2	10.0	0.1	8.0
1969	0.4	6.8	0.3	4.9	0.1	7.2
Ave	0.3	7.1	0.3	4.5	0.2	3.4

Old Field - Hublersburg Soil

Year	6-Inch Depth		24-Inch Depth		48-inch Depth	
	inches per week		inches per week		inches per week	
	0	2	0	2	0	2
1965	0.1	5.1	0.1	8.4	0.3	8.0
1966	0.1	4.3	0.4	7.5	0.1	5.0
1967	0.4	4.6	0.4	12.0	0.3	6.1
1968	0.0	4.8	0.2	4.9	0.2	3.7
1969	0.4	7.3	0.4	8.3	0.2	2.3
Ave	0.2	5.2	0.3	8.2	0.2	5.0

Table 136. Continued.

	Hardwood - Morrison Soil					
Year	6-Inch Depth		24-Inch Depth		48-Inch Depth	
	inches per week		inches per week		inches per week	
	0	2	0	2	0	2
1966	0.2	12.5	0.5	14.9	0.1	10.6
1967	--	16.9	0.5	20.4	1.4	19.2
1968	0.1	22.3	0.2	26.0	0.1	25.9
1969	0.4	17.0	0.1	24.4	0.3	23.7
Ave	0.2	17.2	o.3	21.4	0.5	19.9

	Hardwood - Hublersburg Soil							
Year	6-Inch Depth		24-Inch Depth		48-Inch Depth		72-Inch Depth	
	inches per week		inches per week		inches per week		inches per week	
	0	4	0	4	0	4	0	4
1965	0.1	7.3	--	4.2	--	2.3	--	5.2
1966	0.1	11.1	0.1	9.3	0.1	9.1	--	9.5
1967	0.4	8.6	0.4	5.1	0.3	3.4	--	8.3
1968	0.4	8.8	0.2	3.2	0.1	0.9	--	8.2
Ave	0.3	9.0	0.2	5.5	0.2	3.9	--	7.8

Further support for the importance of denitrification in decreasing the inputs of nitrate to the groundwater was obtained in the data from the Hardwood area on the Hublersburg soil which received four inches of wastewater, weekly, in the April-Nov period (Table 136). The effluent was applied during the week in two 2-inch applications separated by a 2- and 3-day interval. In spite of doubling the nitrogen load, the NO_3-N concentration at 48 inches remained below 10 mg/l, probably because the larger hydraulic load encouraged more denitrification. Results for all of the constituents on the 4-inch plot are given for 1965 to 1967 in Tables A-40 to A-42 in the Appendix and for 1968 in Table 137.

Results for 1968 shown in Table 137 indicate that even at this higher rate of disposal considerable renovation is achieved. Average concentration of constituents and renovation is almost equivalent to that obtained at the 1-inch rate of application even after applying almost 648 inches of effluent from 1963 through 1968. Average concentration

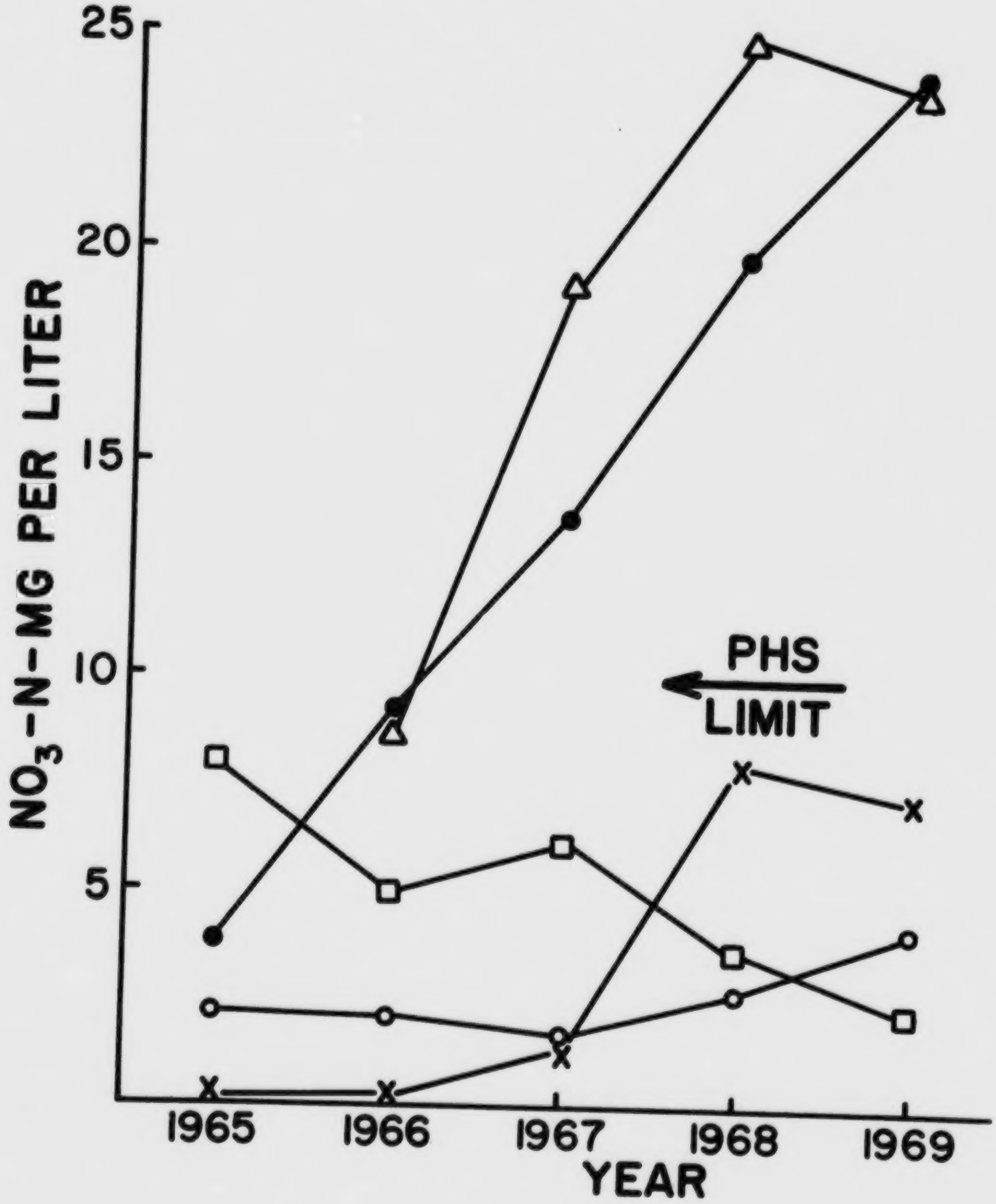

Figure 73. Mean Annual Nitrate-Nitrogen Concentration in Suction Lysimeter Samples at the 48-inch Depth on Various Forest Area. 1965-1969

Table 137. Average Concentration of Constituents in the Applied Sewage Effluent and in the Percolate Water Samples Collected from Pan Lysimeters Located in the Hardwood Plot Which Received 4 Inches of Effluent Per Week During the Period April 15 to October 14, 1968.

	No. of samples	pH	MBAS	NO_3-N	Org-N	NH_4-N	Cl	P	Na	K	Ca	Mg	Mn	B
							Concentration in mg/liter							
Effluent Quality	27	7.7	0.59	5.1	6.4	13.2	46.4	8.455	40.2	18.6	26.4	13.3	0.12	0.37
Soil Depth-inches														
6	51	7.4	0.29	8.8	3.0	9.1	46.3	6.077	41.0	13.7	26.1	13.4	0.09	0.29
12	45	7.4	0.20	6.3	3.2	3.5	55.6	2.821	39.5	12.9	18.3	12.6	0.07	0.27
24	37	7.1	0.09	3.2	0.8	1.0	66.9	0.063	54.6	6.6	10.6	6.8	0.34	0.27
36	31	7.1	0.11	4.4	0.5	1.1	77.3	0.050	53.2	5.3	9.5	9.5	0.36	0.28
48	19	7.4	0.12	0.9	0.9	0.5	53.1	0.050	54.9	3.2	7.1	6.2	0.04	0.12

of MBAS in 1968 at the 4-foot depth was only 0.12 mg/1 in comparison to 0.09 mg/1 on the plot receiving the one inch rate. Similarly, phosphorus concentrations in 1968 were only 0.050 mg/1 (99.4 percent renovation) in comparison to 0.047 mg/1 at the 1-inch per week application. Nitrate-nitrogen concentration in 1968 was extremely low 0.9 mg/1 in comparison to 7.2 mg/1 on the plot receiving one inch. The greater degree of wetness maintained in this area may have triggered more denitrification losses of nitrate in the deeper layers of this fine textured soil.

Renovation efficiency of the 4 inch per week forest plots has remained relatively constant in terms of removing MBAS and phosphorus as shown by the trends of the average annual concentration (Figures 74 and 75).

The large decrease in MBAS in the effluent from 3 mg/1 in 1963 to less than 1 mg/1 in 1968 was the result of improved efficiency of sewage treatment in 1964 and 1965 and of the conversion by the detergent industry from branched to linear alkyl benzene sulfonates.

Average annual concentrations of nitrate-nitrogen varied widely at the various soil depths (Figure 76). No distinct trends are evident except that the average concentration in the percolate has remained less than 10mg.NO_3-N per liter.

Soil Chemical Characteristics

Soil samples were taken to depths of 3 and 5 feet in the fall of 1963 after cessation of irrigation, in the spring of 1964 prior to initiation of irrigation, and again in the fall of 1965. Mean nutrient element concentrations at various depths are given in Tables 138 and 139 for the hardwood 1- and 4-inch irrigated plots and control plot. Soil samples were analyzed for the same constituents as was the effluent to determine if significant concentrations of nutrients were accumulating in the irrigated plots. If so, at what depths were elements concentrating? Was any one group of constituents replacing another group on the soil exchange sites? What was the effect of natural precipitation on nutrient redistribution? What was the change in nutrient status with time?

Total nitrogen was analyzed by the standard Kjeldahl method with modification to include nitrates. The detergent constituent, MBAS, was extracted from the soil with benzene and methanol and analyzed by the methylene blue color method. Chloride was extracted with 0.05N NH_4NO_3 and titrated with an Aminco - Cotlove titrator. Phosphorus was extracted with 0.03N NH_4F in 0.025N HCL using the Bray procedure. Boron and exchangeable cations (K, Ca, Mg, Na, Mn) were extracted with a 1 N NH_4Ac at pH 7.0. The total extract was evaporated to dryness at 105°C and the residue analyzed with an arc emission spectrometer.

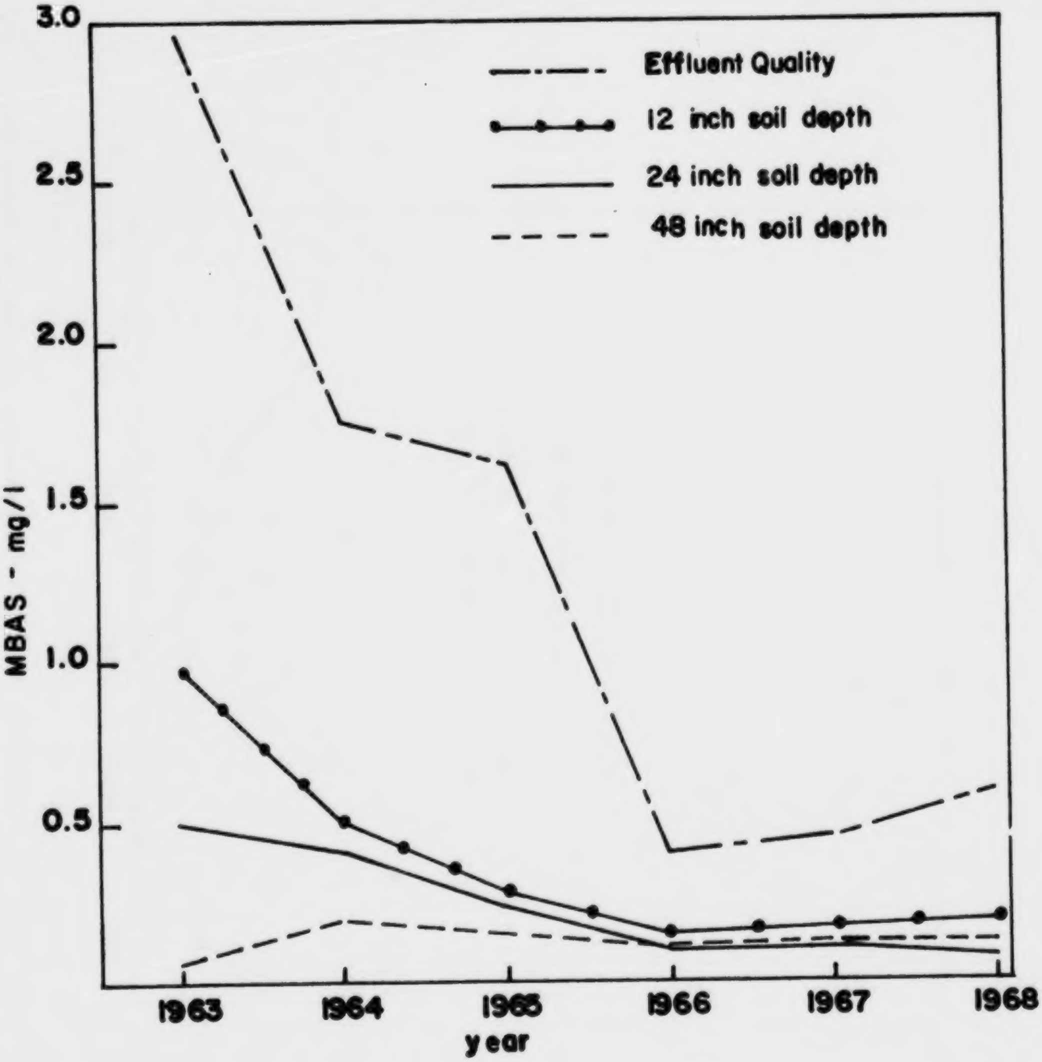

Figure 74. Mean Annual MBAS Concentration in Suction Lysimeter Samples at Three Depths and in the Applied Wastewater in the Hardwood Area on Hublersburg Soil Which Received Four Inches of Wastewater Weekly. 1963-1968

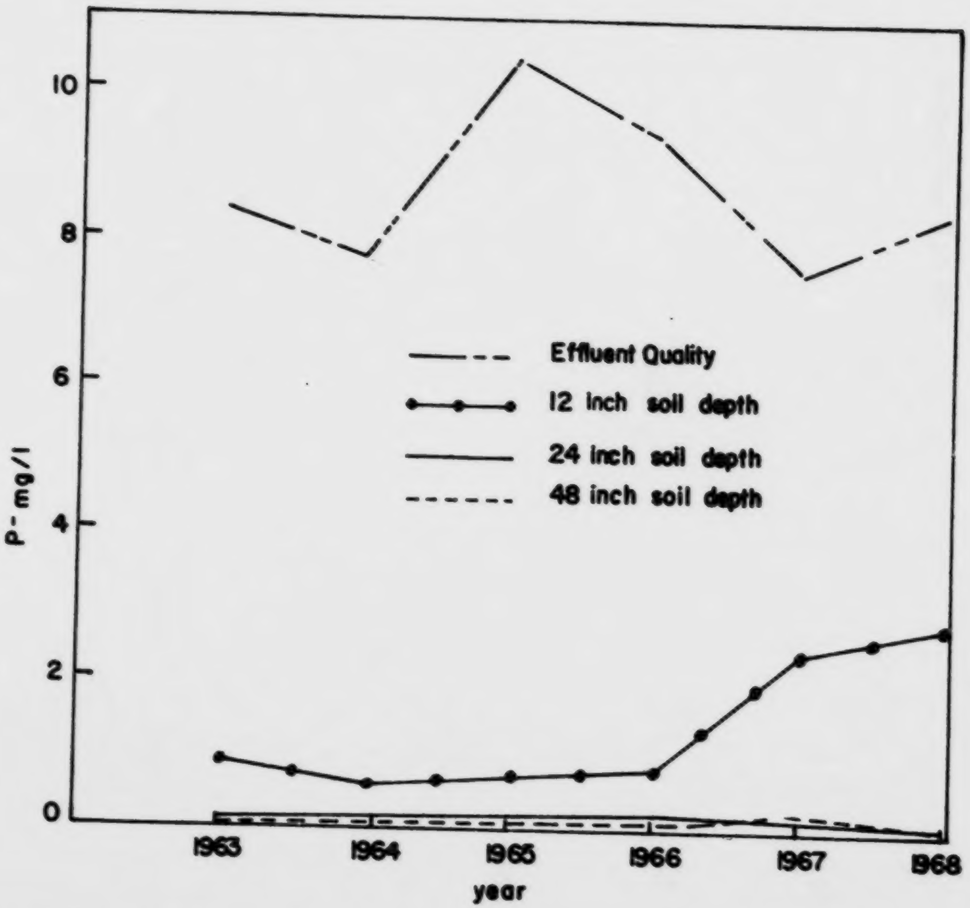

Figure 75. Mean Annual Phosphorus Concentration in Suction Lysimeter Samples at Three Depths and in the Applied Wastewater in the Hardwood Area on Hublersburg Soil Which Received Four Inches of Wastewater Weekly. 1963-1968

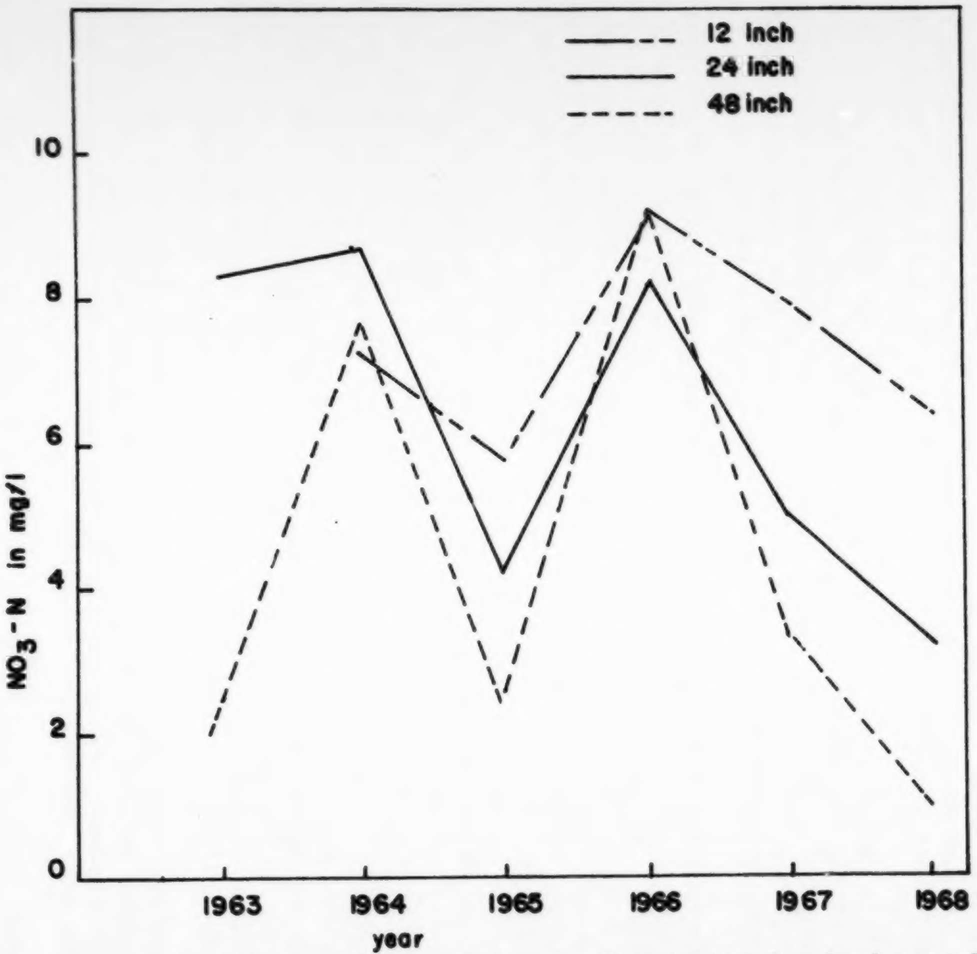

Figure 76. Mean Annual Nitrate-Nitrogen Concentration in Suction Lysimeter Samples at Three Depths in the Hardwood Area on Hublersburg Soil Which Has Received Four Inches of Wastewater Weekly. 1963-1968

Results indicated that there was no significant accumulation in total nitrogen. MBAS content also was not significantly higher in the irrigated plots which appears to indicate that degradation and utilization of MBAS by the soil microorganisms is quite rapid. Phosphorus is readily fixed by the soil so most of it is held in an unavailable form. As shown in Tables 138 and 139, there was a highly significant increase of Bray extractable phosphorus in the upper foot of soil on both irrigated plots. However, phosphorus accumulation is not anticipated to be a problem.

Since the effluent is high in chlorides one would expect that chloride content would be higher on the irrigated plots. Moreover, since chlorides are not strongly adsorbed by soil colloids, they do not attenuate in concentration with increasing depth as does the phosphate.

There was no significant difference between the irrigated and control plots in the amounts of NH_4Ac extractable calcium, magnesium, potassium, manganese, or boron. Although the mean concentrations of calcium and magnesium are higher on the 4-inch irrigated plot than on the control plot, the difference is not statistically significant.

There was a significant increase in exchangeable sodium on all irrigated plots. Significant accumulations were evident to a depth of 3 feet. The maximum content found was less than 0.5 m.e. per 100 g. in the upper foot and less than 0.3 m.e. at greater depths. Under the normal, humid climate of Pennsylvania it is not anticipated that the accumulation of sodium will be great enough to cause a soil structure problem.

A comparison of the soil chemical status at the end of irrigation in 1963 with the soil chemical status in the spring of 1964 prior to the start of irrigation should provide some insight into the extent of desorption and constituent redistribution by leaching (Table 138). A total of 11.66 inches of precipitation occurred during the dormant period and was about average for the area. Averaging the concentration in the upper foot in the spring of 1964 and comparing it with the upper foot in the fall of 1963, only the average concentrations of Na and Mn decreased over the winter. Chloride which one would expect to desorb most readily was present in larger quantities in the spring.

The soil does not appear to be adsorbing or releasing any particular cation or group of cations. The ratio of monovalent cations (Na and K) to divalent cations (Ca and Mg) has remained approximately the same in the irrigated and control plots.

Mean chemical element concentrations in the soil samples collected in the other irrigated areas (red pine 1- and 2-inch plots and open area 2-inch plot) and their respective control areas are given in Appendix Tables A-43 to A-45.

Table 138. Mean Concentration of Chemical Elements in the Soil Samples Collected in 1963, 1964, and 1965 in the Hardwood 1-Inch Treatment and Control Plots.

Depth	N	Cl	Dilute Bray Extr P	Ammonium Acetate Extractable K	Ammonium Acetate Extractable Ca	Ammonium Acetate Extractable Mg	Ammonium Acetate Extractable Mn	Ammonium Acetate Extractable B	Ammonium Acetate Extractable Na	Extr MBAS
feet	%	µg/g	µg/g	me/100g	me/100g	me/100g	µg/g	µg/g	me/100g	µg/g
					TREATMENT					
1963 (Fall)										
1.0	0.068	21.3	24.08	0.39	1.0	0.3	150	0.8	0.30	---
2.0	0.035	12.5	6.77	0.29	0.7	0.9	68	0.4	0.22	---
3.0	0.026	11.5	4.48	0.45	0.8	1.1	72	0.6	0.15	---
1964 (Spring)										
0.5	0.119	22.3	73.36	0.53	1.3	0.6	92	0.8	0.33	---
1.0	0.045	32.1	26.69	0.50	0.6	1.9	90	0.8	0.16	---
2.0	0.041	9.1	11.67	0.47	1.2	0.9	58	0.4	0.27	---
3.0	0.036	51.4	11.99	0.37	1.8	1.5	52	0.6	0.24	---
1965 (Fall)										
0.5	0.216	21.8	204.17	0.91	4.1	1.9	17	0.8	0.47	5.2
1.0	0.071	11.9	130.08	0.62	0.8	0.4	26	0.6	0.24	1.4
2.0	0.034	22.6	9.38	0.76	0.7	0.5	14	0.8	0.28	1.7
3.0	0.031	14.5	6.11	0.67	0.7	1.0	17	0.6	0.23	1.0
4.0	0.024	20.4	3.50	0.82	0.7	1.2	16	0.6	0.26	0.7
5.0	0.020	22.4	2.52	0.45	0.6	1.2	28	0.4	0.20	0.7

Table 138. Continued.

			Dilute Bray Extr	Ammonium Acetate Extractable						
Depth	N	Cl	P	K	Ca	Mg	Mn	B	Na	Extr MBAS
feet	%	µg/g	µg/g	me/100g	me/100g	me/100g	µg/g	µg/g	me/100g	µg/g
					CONTROL					
1963 (Fall)										
1.0	0.134	5.7	88.29	0.31	1.4	0.3	208	0.4	0.19	---
2.0	0.061	9.0	16.24	0.34	1.7	1.3	104	0.2	0.20	---
3.0	0.042	7.2	4.81	0.42	1.6	1.8	75	0.4	0.18	---
1964 (Spring)										
0.5	0.239	21.8	42.70	0.58	2.6	0.4	334	0.4	0.21	---
1.0	0.066	10.8	24.41	0.23	0.8	0.4	98	0.4	0.22	---
2.0	0.054	12.9	4.48	0.37	1.2	1.2	64	0.2	0.22	---
3.0	0.039	11.5	1.54	0.42	1.3	2.1	44	0.2	0.26	---
1965 (Fall)										
0.5	0.281	7.7	43.35	0.94	4.2	0.5	46	0.8	0.22	4.5
1.0	0.073	7.1	30.94	0.56	0.6	0.3	24	0.6	0.09	2.3
2.0	0.026	5.4	11.34	0.62	1.1	0.8	15	0.8	0.16	3.0
3.0	0.025	7.5	6.43	0.62	1.3	1.5	10	0.6	0.10	0.8
4.0	0.016	17.0	4.15	0.59	0.9	1.2	9	0.6	0.16	0.8
5.0	0.016	16.3	3.50	0.73	0.9	1.4	11	0.8	0.18	0.5

Table 139. Mean Concentration of Chemical Elements in the Soil Samples Collected in 1965 in the Hardwood 4-Inch Treated Plot.

			Dilute	Ammonium Acetate Extractable						
Depth	N	Cl	Bray Extr P	K	Ca	Mg	Mn	B	Na	Extr MBAS
feet	%	μg/g	μg/g	me/100g	me/100g	me/100g	μg/g	μg/g	me/100g	μg/g
TREATMENT										
1965 (Fall)										
0.5	0.160	8.4	556.67	1.18	6.5	3.1	6	1.0	0.39	3.5
1.0	0.044	2.7	251.42	0.79	1.6	1.2	10	0.6	0.29	1.2
2.0	0.033	10.0	34.53	0.82	1.2	0.9	9	0.8	0.36	0.5
3.0	0.033	5.9	8.73	0.64	2.2	2.9	8	0.4	0.39	0.4
4.0	0.022	20.3	12.32	0.64	2.2	2.5	7	0.6	0.36	0.3
5.0	0.016	22.5	18.53	0.61	1.9	1.9	9	0.6	0.27	0.5
CONTROL										
Control Plot is the same as for the hardwood 1-inch.										

Nutrient Composition of Foliage

Foliar samples from the hardwoods, red pines, white spruce, and ground vegetation in the old-field plot were collected and analyzed to determine the extent of utilization of the nutrient elements in the sewage effluent. Results for the analyses of samples collected at the end of the growing season in 1965, 1966 and 1967 are given in Tables 140 to 142. The nutrient element content in the foliage of the vegetation on the irrigated plots in 1967 was generally higher in nitrogen, phosphorus, magnesium, boron, and sodium and lower in manganese than that in the vegetation on the control plots. It is therefore obvious that this higher concentration together with a generally greater growth of the forest vegetation is at least temporarily contributing to the renovation of the percolating effluent; however, its ultimate contribution is difficult to estimate because the annual storage of nutrients in the woody tissue and the extent of recycling of nutrients in the forest litter are extremely difficult to measure.

Although considerable amounts of nutrients may be taken up by trees during the growing season, many of these nutrients are redeposited annually in the leaf and needle litter rather than being hauled away as in the case of harvested agronomic crops.

Tree Growth Responses

Diameter and height growth measurements were made annually on sample trees selected at random on each irrigated and control plot. Average annual diameter growths for the red pine and mixed hardwood plots are given in Table 143. Results indicated that weekly irrigation of red pine with 1 and 2 inches of sewage effluent did not significantly increase diameter growth. In fact, it is quite obvious that the 2-inch per week application actually caused a significant decrease in diameter growth.

Average annual diameter growth of the mixed hardwood species was not affected by the 1-inch per week application on the older stand but was significantly increased on the younger stands which received 2 or 4 inches per week. Annual increases in diameter growth ranged from 27 to 200 percent.

Results of the height growth measurements in the red pine plots are given in Table 144. Irrigation with sewage effluents at both rates produced slight increases in height growth during the first 2 years. This slight increase in height growth has been maintained in the plot receiving 1 inch per week, however, during the last 4 years height growth on the plot receiving 2 inches per week has been significantly reduced. In addition the needles in the upper part of the canopy were starting to turn yellow. In 1968, high winds following a wet snowfall completely felled every tree on the 2-inch plot. The plot

Table 140. Average Chemical Content of Tree Foliage and Old Field Ground Vegetation at the End of the 1965 Irrigation Season.

Plot	N	P	K	Ca	Mg	B
Farm Woodlot Area		Percent of dry weight				µgm/gm
Hardwood 1-inch						
Irrigated	2.49	.167	1.04	0.83	.140	98
Control	2.62	.156	1.13	0.90	.114	48
Red Pine 1-inch						
Irrigated	1.58	.152	0.73	0.26	.085	27
Control	1.23	.160	0.81	0.22	.094	22
Red Pine 2-inch						
Irrigated	1.98	.142	0.66	0.24	.087	29
Control	1.26	.162	0.86	0.21	.078	21
Old Field 2-inch						
Irrigated	2.66	.366	2.25	1.35	.396	55
Control	1.29	.133	1.52	1.12	.152	42
Gameland Area Hardwood 2-inch						
Irrigated	3.05	.218	1.22	0.83	.140	111
Control	2.18	.146	1.08	0.62	.103	47
Gameland Area Hardwood 4-inch						
Irrigated	3.04	.244	1.22	0.73	.130	106
Control	2.31	.152	1.24	0.83	.120	48

Table 141. Average Chemical Content of Tree Foliage and Old Field Ground Vegetation at the End of the 1966 Irrigation Season.

Plot	N	P	K	Ca	Mg	B	Na
	Percent of dry weight					μgm/gm	μgm/gm
Farm Woodlot Area							
Hardwood 1-inch							
Irrigated	2.41	0.137	0.95	0.71	0.157	104	14
Control	2.29	0.130	1.06	0.75	0.125	52	12
Red Pine 1-inch							
Irrigated	1.75	0.180	0.59	0.25	0.084	33	84
Control	1.17	0.166	0.57	0.19	0.082	20	9
Red Pine 2-inch							
Irrigated	2.18	0.142	0.58	0.25	0.091	29	83
Control	1.34	0.169	0.63	0.19	0.070	22	16
Old Field 2-inch							
Irrigated	2.74	0.344	2.10	1.19	0.426	62	395
Control	1.45	0.158	1.37	1.06	0.165	34	28
White Spruce 2-inch							
Irrigated	2.38	0.247	0.55	0.51	0.086	38	56
Control	1.56	0.163	0.56	0.55	0.084	17	6
Gameland Area							
Hardwood 2-inch							
Irrigated	2.75	0.179	1.07	0.61	0.185	93	12
Control	3.23	0.141	1.20	0.80	0.129	57	12
Hardwood 4-inch							
Irrigated	3.03	0.186	1.11	0.53	0.212	102	12
Control	3.23	0.141	1.20	0.80	0.129	57	12

Table 142. Average Chemical Content of Tree Foliage and Old-Field Ground Vegetation at the End of the 1967 Irrigation Season.

Plot	N	P	K	Ca	Mg	Mn	Fe	Cu	B	Al	Zn	Na
	Percent of dry weight					µg/g						
Farm Woodlot Area												
Hardwood 1-inch												
Irrigated	2.45	0.22	0.86	1.00	0.14	1500	88	8	81	68	26	15
Control	2.20	0.18	0.87	0.99	0.08	1845	80	7	49	66	27	16
Red Pine 1-inch												
Irrigated	1.62	0.17	0.58	0.19	0.09	942	41	4	28	142	33	44
Control	1.15	0.16	0.53	0.29	0.09	1103	53	4	19	496	45	8
Red Pine 2-inch												
Irrigated	2.17	0.13	0.52	0.26	0.10	947	58	4	33	97	32	114
Control	1.33	0.15	0.61	0.24	0.08	925	54	3	23	394	40	11
Old-Field												
Vegetation 2-inch												
Irrigated	3.28	0.45	2.34	1.23	0.44	235	379	19	39	825	94	473
Control	1.30	0.16	1.19	1.09	0.13	642	400	13	35	958	95	28

Table 142. Continued.

Plot	N	P	K	Ca	Mg	Mn	Fe	Cu	B	Al	Zn	Na
	Percent of dry weight					µg/g						
White Spruce 2-inch												
Irrigated	2.19	0.29	0.67	0.84	0.12	517	90	6	38	87	35	117
Control	1.48	0.19	0.71	0.93	0.13	834	57	5	26	100	95	10
Hardwoods 2-inch[1]												
Irrigated	2.97	0.29	0.93	0.77	0.19	1830	81	7	117	50	33	13
Control	2.20	0.18	1.13	1.01	0.09	2725	83	8	65	80	25	16

Table 143. Average Annual Diameter Growth for Period 1964 to 1969.

Plot	1964	1965	1966	1967	1968	1969	Average diameter growth
	inches	inches	inches	inches	inches	inches	inches
Red pine 1-inch	0.10	0.08	0.07	0.13	0.07	0.05	0.08
Red pine control	0.10	0.09	0.12	0.14	0.08	0.08	0.10
Red pine 2-inch	0.07	0.05	0.07	0.09	0.04	-	0.06
Red pine control	0.13	0.11	0.12	0.15	0.09	0.08	0.11
Mixed hardwood 1-inch	0.16	0.18	0.16	0.13	0.12	0.16	0.15
Mixed hardwood control	0.15	0.15	0.16	0.14	0.17	0.18	0.16
Mixed hardwood 2-inch			0.15	0.29	0.24	0.23	0.23
Mixed hardwood control			0.05	0.12	0.11	0.14	0.10
Mixed hardwood 4-inch		0.22	0.19	0.23	0.14[1/]	0.25[1/]	0.21
Mixed hardwood control		0.13	0.15	0.15	0.13	0.20	0.15

[1/] Winter irrigation only.

Table 144. Average Annual Terminal Height Growth in the Red Pine Plots During the Period 1963 to 1968.

Plot	1963	1964	1965	1966	1967	1968	Average height growth
	feet	feet	feet	feet	feet	feet	feet
Red pine 1-inch	1.2	2.1	2.0	1.7	1.8	1.7	1.7
Red pine control	1.2	1.6	1.3	1.4	1.6	1.5	1.4
Red pine 2-inch	1.5	2.2	1.6	1.4	1.5	1.3	1.6
Red pine control	1.4	2.0	1.9	1.8	1.6	1.6	1.7

Table 145. Average Annual Height Growth of White Spruce

Plot	1963	1964	1965	1966	1967	1968	1969	Average height growth
	feet	feet	feet	feet	feet	feet	feet	feet
White Spruce 2-inch	0.97	2.19	1.74	2.04	2.18	2.28	2.10	1.92
Control	0.83	1.35	0.58	0.75	0.88	1.43	1.46	0.92
Percent Increase	17	62	200	172	148	60	44	108

was cleared in 1969 and replanted with white pine seedlings which have been shown to be more adaptable to irrigation with sewage effluent on this fine textured soil.

Height growth response of the white spruce saplings which received 2 inches of effluent per week was significantly increased. During the 7 years of irrigation average annual height growth of the irrigated trees was 1.92 feet in comparison to 0.92 feet on the control plot. (Table 145). Average annual height growth was significantly increased by 62 to 200 percent. At the start of the study, the height of the white spruce ranged from 3 to 8 feet. At the end of the growing season in 1969, the average height of the trees on the control plot was 6 feet and on the irrigated plot 18 feet.

Herbaceous Vegetation Growth Responses

Transect plots were also established in the old field spruce stand to measure growth responses of the ground vegetation and to determine the effect of sewage effluent on site productivity. Average annual dry matter production on the irrigated plot was 5,532 pounds per acre in comparison to 1,650 pounds per acre on the control plot (Table 146). This represents an average annual increase of 235 percent. Annual increases ranged from approximately 100 to 350 percent. Average height of the predominant plant species was 4.4 feet on the irrigated plot in comparison to 1.3 feet on the control plot. In addition, approximately 10 percent of the control plot was barren of vegetation; whereas, the irrigated plot had a complete dense vegetation cover.

Table 146. Growth Response of Ground Vegetation in the Open White Spruce Plots, Expressed in Terms of Dry Matter Production.

Year	Irrigated Plot	Control Plot
	lbs/acre	lbs/acre
1963	3,381	1,470
1964	7,607	1,763
1965	5,672	1,675
1966	6,417	1,435
1967	4,075	2,010
1968	6,044	1,550
Average	5,532	1,650

Tree Seedling Survival and Growth Study

Eight tree species were also planted in an open field area in 1965 to determine which species might be best suited for sites to be used as disposal areas for sewage effluent. One- and two-year-old seedlings of European larch (Larix decidua), Japanese larch (Larix leptolepis), white pine (Pinus strobus), red pine, white spruce, pitch pine (Pinus rigida), Austrian pine (Pinus nigra), and Norway spruce (Picea abies) were planted in a randomized block design with three blocks irrigated with 2 inches of effluent per week and three blocks maintained as a control. Each block contained 10 trees of each species or a total of 80 trees per block. First-year survival (1965) over all species on the irrigated plot was 88 percent and on the control plot, 52 percent (Table 147). Continued irrigation with wastewater resulted in average

Table 147. Survival of Planted Tree Seedlings - 1965-1969.

	Year							
	1965		1966		1967		1969	
Species	A[1]	B	A	B	A	B	A	B
	Survival - percent							
White pine	100	87	80	60	70	50	70	20
Red pine	100	93	77	77	53	53	43	23
Norway spruce	97	46	77	13	57	13	47	7
White spruce	97	33	63	20	43	13	33	3
Pitch pine	93	80	33	50	10	20	3	3
Austrian pine	90	47	30	47	13	40	13	17
European larch	80	23	30	10	23	6	23	0
Japanese larch	47	7	20	6	17	0	17	0
Average	88	52	51	35	36	24	31	9

[1] A = irrigated; B = control

survivals of 31 percent and 9 percent in 1969 on the irrigated and control areas.

The total height growth of surviving seedlings at the end of the growing season in 1969 is shown in Table 148. Results indicate that European and Japanese larch and white pine had the greatest growth response to sewage effluent irrigation.

Table 148. Average Total Height Growth of Surviving Seedlings in the First Year, 1965, and in 1969.

Species	Total Height Growth - feet			
	Irrigated		Control	
	1965	1969	1965	1969
European larch	0.38	6.8	0.04	1/
Japanese larch	0.46	6.4	0.03	1/
White pine	0.28	5.1	0.18	2.1
Red pine	0.28	3.0	0.15	1.6
White spruce	0.20	2.9	0.15	2.2
Pitch pine	0.24	2.9	0.10	1.0
Austrian pine	0.20	2.7	0.17	1.9
Norway spruce	0.22	2.4	0.25	1.4

1/ No trees survived in 1969.

SECTION VIII

GEOHYDROLOGY

MONITORING RESULTS

Data obtained from chemical analyses of soil-water collected from depths of 6 to 26 feet below landsurface are considered here together with data from on and offsite deep monitoring wells at depths of 100 to 370 feet. Chemical data are presented for only selected monitoring points to show the ranges in conditions encountered. Data showing the best and worst conditions experienced on site are given along with more representative data.

Procedures

Considerable variability in chemical quality may result due to daily, weekly and monthly variations in precipitation, farming practice, and other factors.

Some scatter in water quality values also may be considered as aberrant values because there is reason to believe that data from contaminated samples may have been included in the mass of data obtained. Examples may be isolated from the data where an abnormally high concentration of a particular constituent was recorded which is preceded and followed by a sequence of much lower values. This casts doubt on the occasional, isolated aberrant values particularly for waste constituents such as phosphorus which does not have the mobility implied by the data. In some samples, particularly from shallow sand point wells, suspended sediment which was not obviously present interfered with the chemical analysis procedure for phosphorus. Such aberrant values usually fell at the upper end of the range.

All data were included in the quality frequency plotting discussed below. The aberrant phosphorus values were removed prior to computing the analysis of variance of the yearly means and applying the Duncans multiple range test of the difference between annual means.

In the frequency plotting the quality data are tabulated in descending order of magnitude and the equation $P_m = m/(N_W+1)\ 100$ (95) is used to assign relative frequencies of samples whose concentrations are equal to or greater than the concentration of a particular sample. In this equation m is the order number of the sample concentration value, N_W is the total number of samples and P_m is the percent of samples whose concentrations are equal to or greater than the concentration of sample with order number m. In plotting the concentration values against P_m on a logarithmic probability scale it is assumed that the observations are a random sample from a log normally distributed population. If a straight line is fitted to the array of values in such a plot the slope

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will be steep if the range of concentrations is wide and flat if the range is narrow. For lines of equal slope, the higher the position of the line the greater is the median concentration. The time sequence of sampling is ignored in the frequency displays but the effects of time may be considered in a general way by comparing the arrays of data grouped for one time period with that of another time period. Some three and four year displays are given for several off-site and on-site wells. The statistical significance of the displacement of the arrays was not evaluated but an analysis of variance procedure and Duncans Multiple Range test was used to evaluate the significance of the differences of the annual means of twelve of the monitoring wells (Tables 149 - 151).

Agronomy-Forestry Area

Well Characteristics. Figure 2 shows the proximity of monitoring wells to the Agronomy-Forestry Site. F-1, 2, 3, 4, and 5 and UN-14 are the principal onsite wells. F-1, 2, and 5 are closest to irrigation plots; F-4, UN-14 and F-3 are further away. Each well site was selected to provide control under a set of specific conditions. UN-14, for example, is a university water supply well with a potential capacity of in excess of 500 gpm. It routinely produced from 150 to 250 gpm since 1964. This well intercepts a considerable portion of the reclaimed effluent which is diverted to the nearby University well field shown in Figure 2.

It has been shown by Parizek (96), Siddiqui and Parizek (97) and Parizek (98) that valley bottoms such as Big Hollow tend to favor permeability development within carbonate rocks for a variety of reasons that include an interaction of structure, rock type, surface and groundwater flow. Parizek (98) showed five basic mechanisms that are involved in developing anisotropic permeability beneath the valley environment that have a bearing on the location of monitoring well UN-14.

Big Hollow is a dry underdrained karst valley all but for brief periods of the year when perched runoff may occupy segments of the valley. Water enters the surface by diffuse infiltration along somewhat permeable flood plain deposits, and within small sinkholes. The water table underlay this valley by 15 to 35 feet or more when the first University supply wells were drilled in Big Hollow. The course of Big Hollow is in part controlled by the more soluble Stonehenge Limestone which now serves as the eastern valley wall, by intersecting zones of fracture concentration which help to localize the center of the valley and its dry tributaries, and which add greatly to bedrock permeability, and locally by systematic joint sets and fault zones. These structural and stratigraphic factors have combined to localize permeability development along with concentrated solution of dolomite and limestone within the valley environment (98).

Aside from the higher productivity of wells located within this valley compared with wells drilled into similar rock on adjacent uplands, the increased permeability along the valley bottom of Big Hollow is revealed by the water table maps shown in Figures 4 and 5. Water table contour lines extend up and down the valley in response to pumping in the University well field following more permeable strata. This has produced an elongate cone of depression typical of rocks with anistropic permeability characteristics. These water table lows mark groundwater drains or avenues of increased groundwater flow which may extend for a mile or more up and down the valley. A 1969 water table contour map subsequent to the 1965 map shown in Figure 5 shows this more dramatically. The map had added control points to the southwest that helped to better define this relationship but is not included here because few control points were available at the irrigation sites.

Well UN-14, obtains its water by lateral flow from groundwater mounds located on either side of the valley walls of Big Hollow including flow from the Agronomy-Forestry irrigation site as well as flow up and down Big Hollow. Water quality data for UN-14, therefore, represents a blend of water reflecting diverse land uses in addition to effluent disposal. These include occasional runoff from University barnyards during periods of rapid snow melt and rainfall, use of road salt to control snow and ice along Fox Hollow Road to the southwest of the irrigation area, farming and grazing in fields adjacent to UN-14, manure disposal in fields immediately east and south of UN-14 and routine liquid sludge disposal in a sinkhole-foundation excavation located between F-4 and F-6 in Big Hollow. Sludge disposal at that site was terminated in 1964 but residual effects are to be expected.

A zone of fracture concentration extends from immediately adjacent to UN-14 back to the region of F-1 where reed canarygrass and red pine plantations were irrigated. This zone of fracture concentration is an avenue of high permeability as revealed by the favorable yield of UN-14 drilled near to the zone, and evidence of well developed solution features observed in the field along the zone of fracture concentration.

F-1 is not on a zone of fracture concentration, but was located on a groundwater high, which dissipated somewhat during drought years, 1962-1967, in response to heavy pumping in the University well field. It intercepted water that was being diverted to the well field until it failed for mechanical reasons early in 1970.

F-2 is on the zone of fracture concentration on which UN-14 was drilled. It was centrally located in the irrigation plots until 1969 when the New Red Pine irrigation ceased. Severe flowing sand problems, and falling water levels reduced its use and eventually eliminated this well from the monitoring program. Because of its small diameter

(3 inches) and extensive casing already set, this well could not be deepened and maintained as a monitoring well.

F-3 is on a zone of fracture concentration in sandy dolomite and in a valley-bottom tributary to Big Hollow. This setting favors high permeability development within the rocks underlying the valley for the reasons stated above. The area receives surface runoff from adjacent areas during the spring snow melt. The well is located where residual soils have been thinned by erosion. Dolomite is exposed at isolated outcrops along the valley walls. F-3 is located between the irrigated area and nearby private wells located to the northeast (Wells 30 and 40, Fig. 2).

F-4 is down gradient in the direction of groundwater flow from the 2-inch red pine disposal area, and more remote from a zone of fracture concentration. Groundwater moves beyond F-4 to avenues of high permeability below Big Hollow and then up valley to the University well field.

F-5 is at the intersection of two zones of fracture concentration which divert water from the reed canarygrass plots, red pine plantations and abandoned field irrigation plots. The well is immediately adjacent to the reed canarygrass irrigation area which receives 2-inches of effluent on a year around basis. It intercepts water moving toward UN-14 and other wells in the University well field along zones of fracture concentration and recharge water derived from spring runoff. Runoff derived from the reed canarygrass area moves by overland flow past F-5 for at least 100 to 500 feet to the southeast before completely infiltrating into the soil within a wood lot. This condition occurs about two or three days out of each year on the average.

Water Quality. It may be seen from Figure 77 , that the chloride concentration in UN-14 ranged from .09 to 2.5 ppm in 1966, less than .01 to 4.6 ppm in 1967, and from less than .01 to 7.2 ppm in 1968. Median values increased from .55 to 1.0 to 3.2 ppm consecutively for these same years. The comparatively high chloride concentrations observed for 1968 compared with the two previous years is attributed in part from other land uses discussed earlier. This suggests that nearly five years were required before reclaimed effluent migrated from the Agronomy-Forestry plots in sufficient volume to be detected on the assumption that the reclaimed effluent was an important if not a principal source of chloride in UN-14. This delay is reasonable in view of the fact that only about 12 acres were irrigated during the growing season of 1963, approximately 33 acres during the growing season of 1964 through 1971 and that winter irrigation was not initiated in the reed canarygrass area until 1965. More than one year, for example, was required to cause a buildup in chlorides in FM-18 which is a 26 foot deep screen well completed in perched groundwater in residual soil. This shows that chlorides moved slowly through the

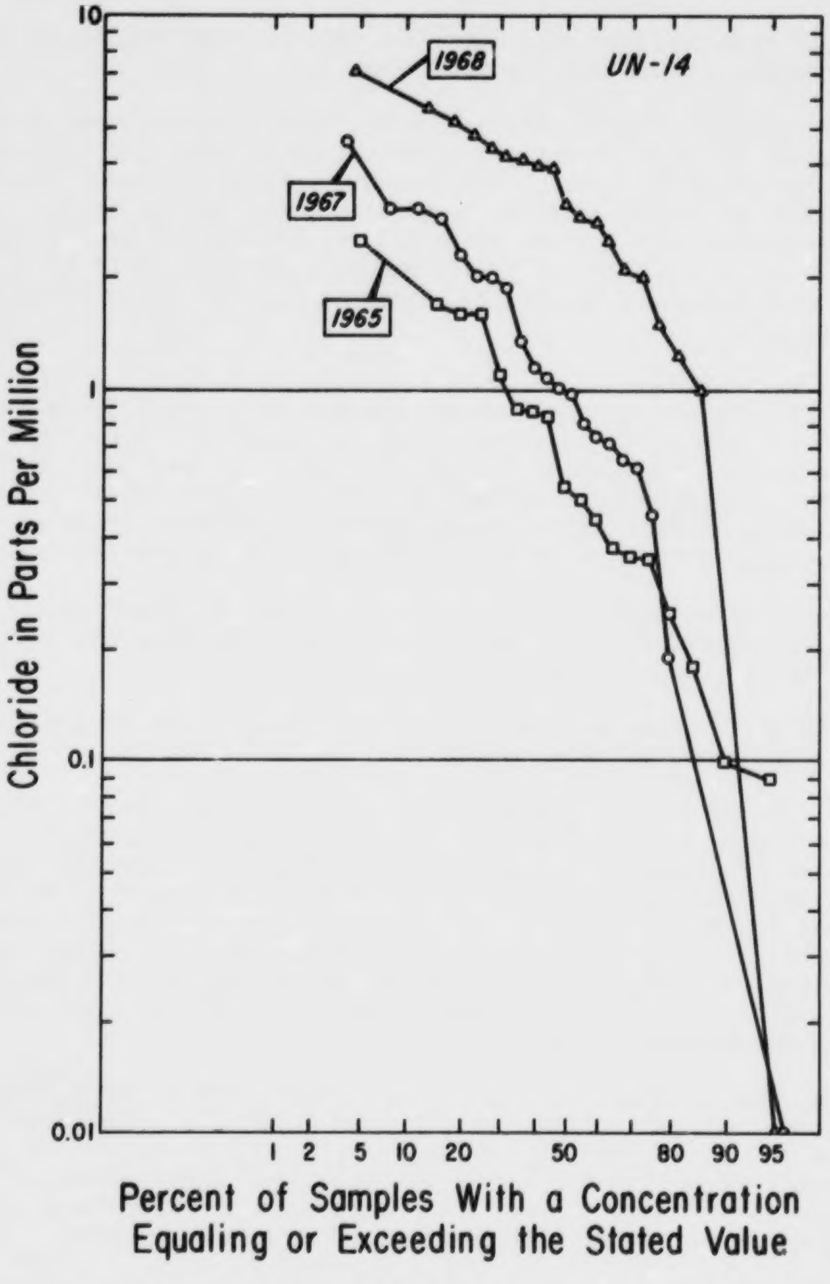

Figure 77. Percent of UN-14 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values.

clay rich residual soil under the soil moisture regime and irrigation schedule experienced the first year.

Alternately, with a return to near normal precipitation in 1967 and normal or above normal precipitation since 1967, the chloride increases noted in UN-14 might be attributed mostly to increased runoff from roads and fields adjacent to UN-14 and the various sources of chloride associated with the use of road salt, leaching of manures applied to fields on two sides of UN-14, and greater runoff into Big Hollow from somewhat distant University barns and new service buildings and parking lots.

Nitrate-nitrogen also showed increases in UN-14 in 1967 and 1968 (Fig. 78). Nitrate-nitrogen showed a range of 1.4 to 2.3 ppm and a median of 1.7 ppm in 1966, 1.4 to 4.9 and a median of 2.6 ppm in 1968, 1.8 to 5.6 and a median of 3.0 ppm in 1968. The 1967 and 1968 plots are very similar and may reflect increased rainfall in 1967 that may have flushed nitrate-nitrogen from nearby agricultural lands as well as the eventual arrival of reclaimed effluent from the nearby irrigation site.

The apparent ABS values in Figure 79 are not significantly different from background values and are substantially below the recommended limit for potable water.

The UN-14 phosphorus values have not changed significantly and fluctuate around a median value of about 0.02mg P/l. (Fig. 80)

F-3 shows no significant changes in phosphorus, ABS, or NO_3-N for the period 1965-1968. The well is stratigraphically located in the direction of groundwater flow to points of natural discharge along Spring Creek (Fig. 2 and 5) and is between the irrigated areas and nearby private wells. Results are important because they show that after 6 years of irrigation, groundwater quality 350 feet beyond the outer fringe of irrigation remained similar to that of background water quality. Chloride increased slightly by 1968 but still remained within the background range.

Phosphorus values equalled or exceeded by 80% of the values ranged from .002 and .003 ppm for the years 1965, 1966, 1967 and 1968 (Fig. 81). The median (50%) values were less than .02 ppm and the values equalled or exceeded by 20% of the values ranged between .02 and .03 ppm for the four years. These are within the background range for groundwater essentially unaffected by man's activities.

The ABS median values for F-3 (Fig. 82) ranged from .02 to .04 ppm. This range is within the variation associated with determination of apparent ABS by the methylene blue method.

NO_3-N for F-3 remained at background levels for the four years considered (1965-68) (Fig. 83). These values are typical of groundwater in the local carbonate aquifers that are little influenced by

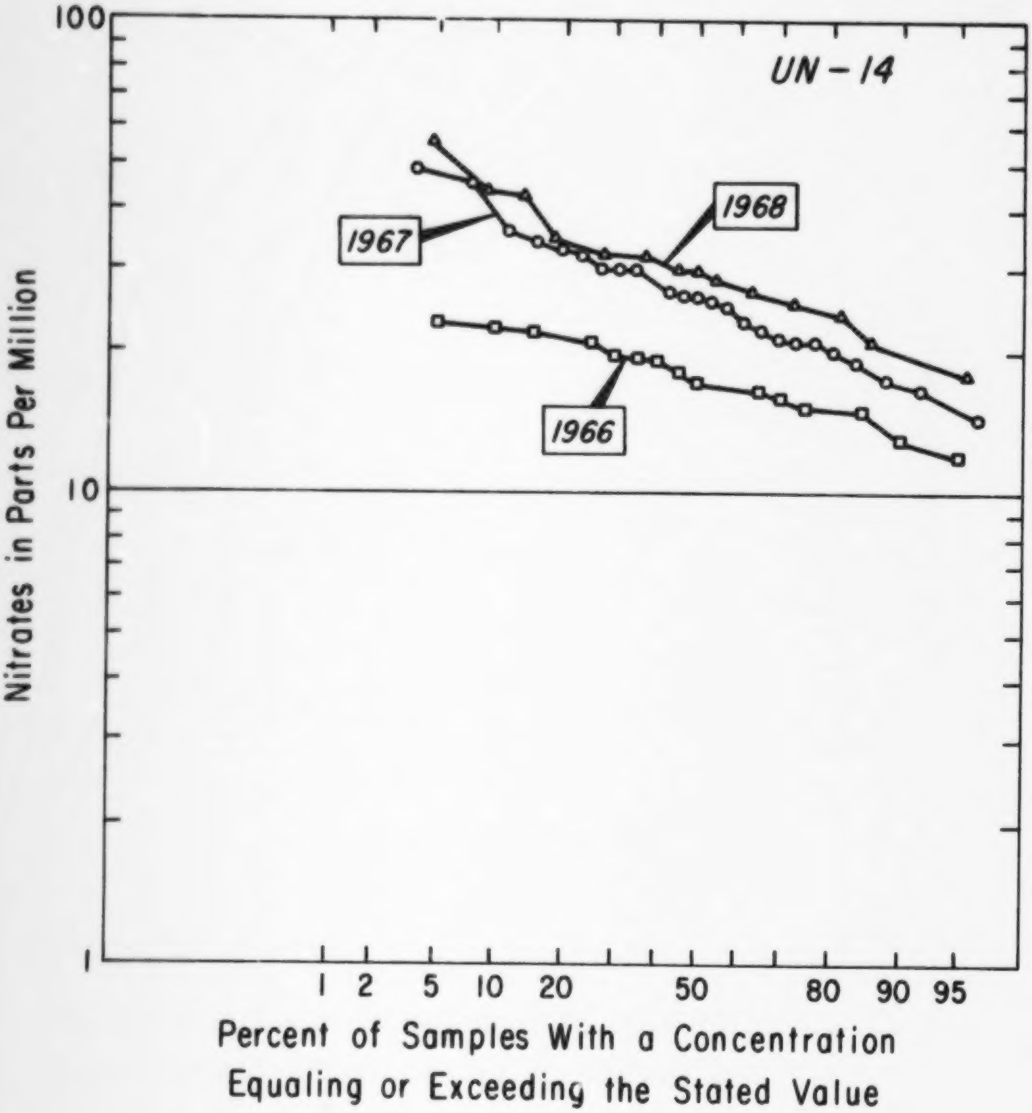

Figure 78. Percent of UN-14 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values.

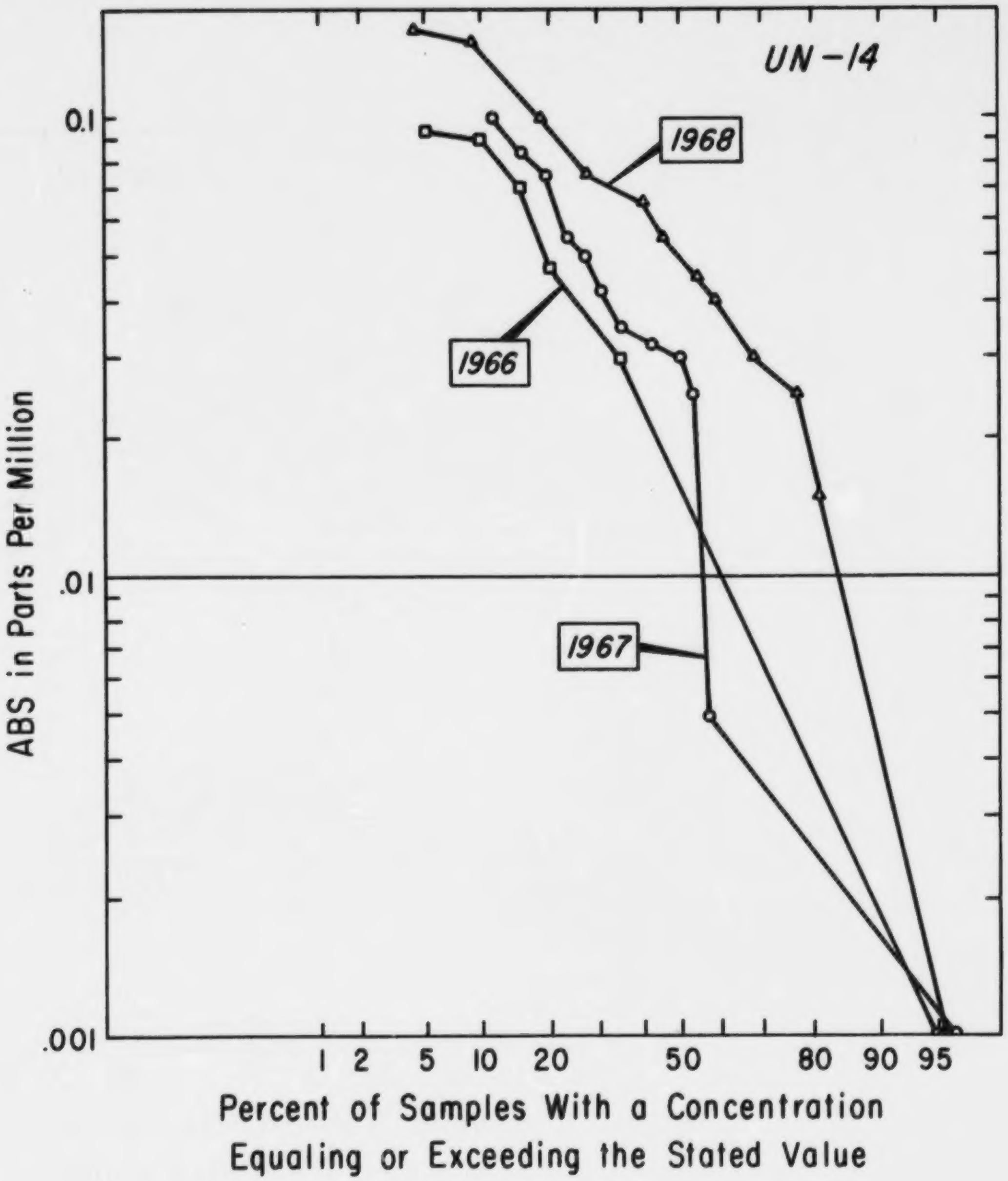

Figure 79. Percent of UN-14 Deep Well Samples with ABS Concentrations Equalling or Exceeding State Values.

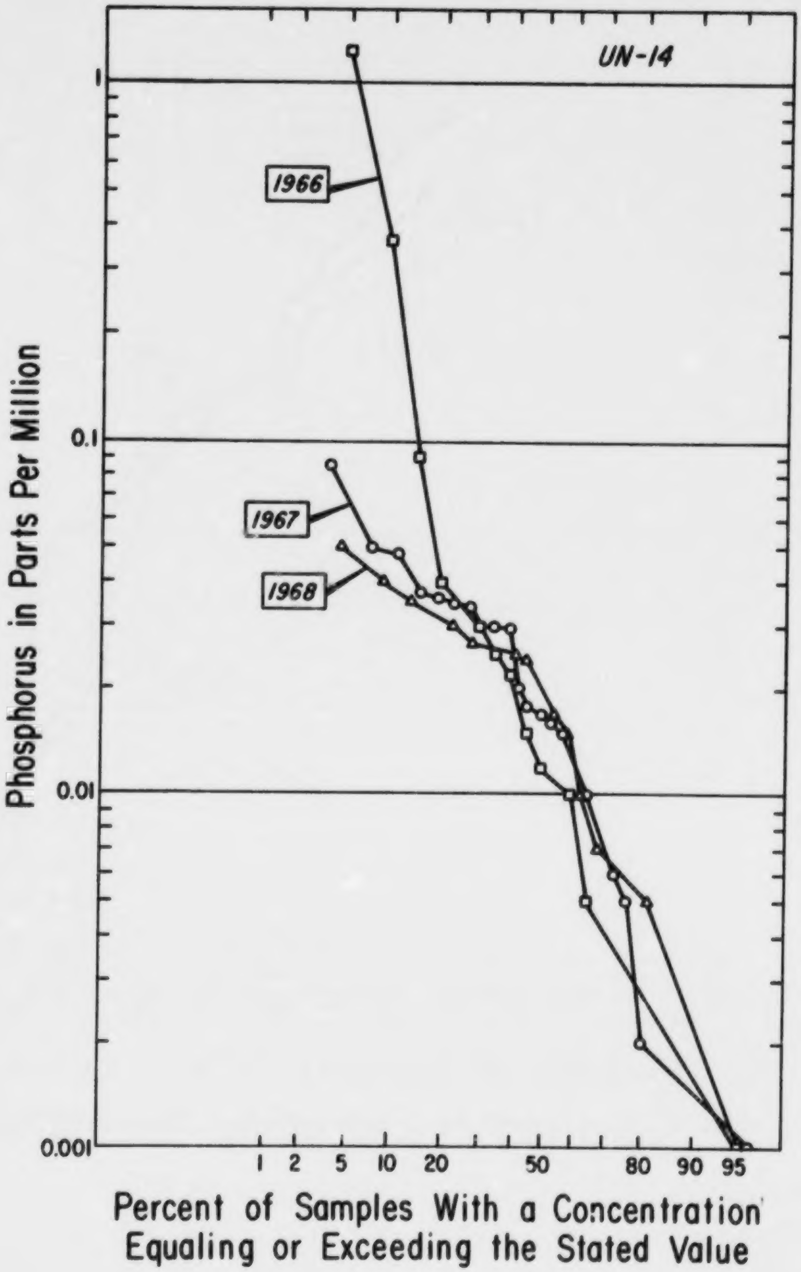

Figure 80. Percent of UN-14 Deep Well Samples with P Concentrations Equalling or Exceeding Stated Values.

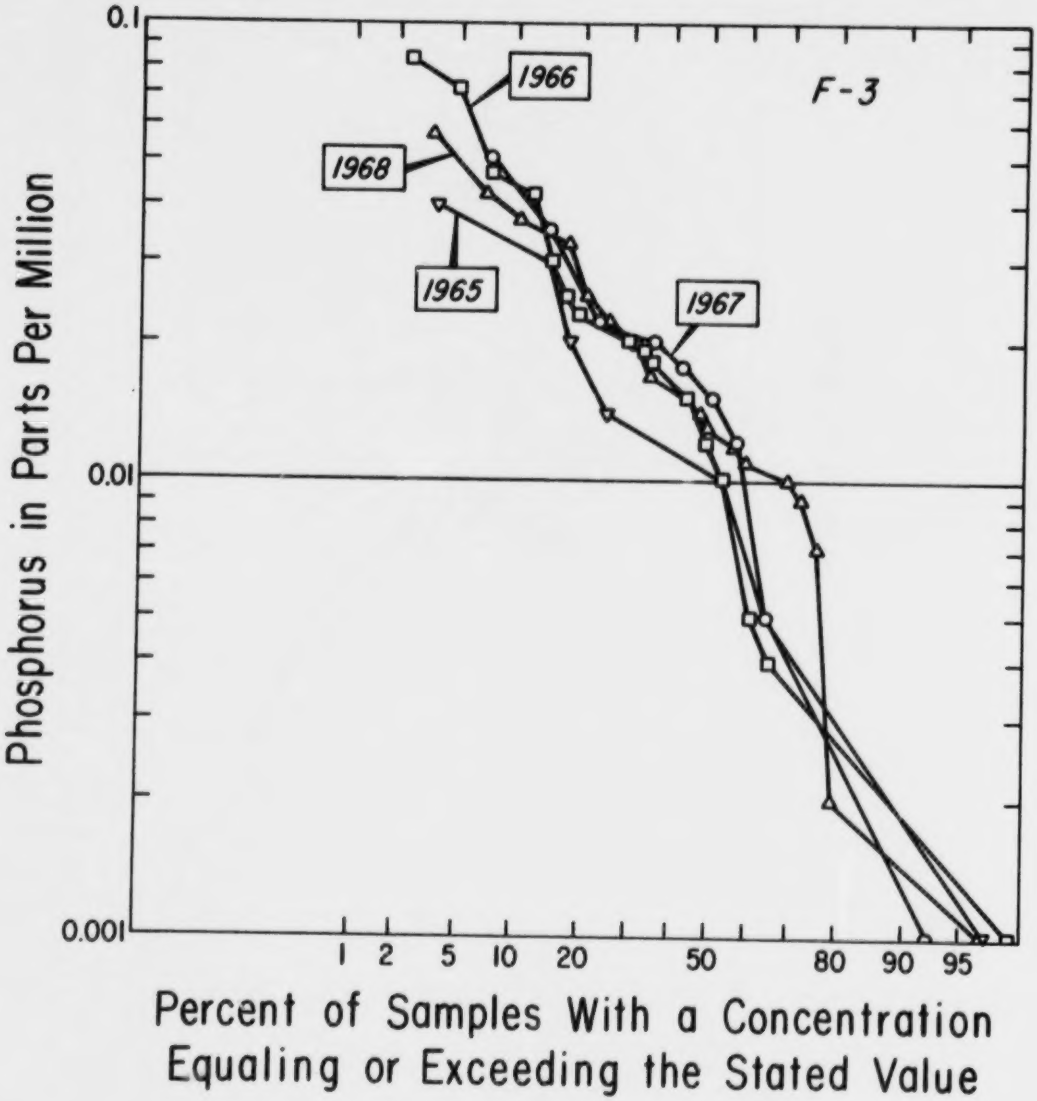

Figure 81. Percent of F-3 Deep Well Samples with P Concentrations Equalling or Exceeding Stated Values.

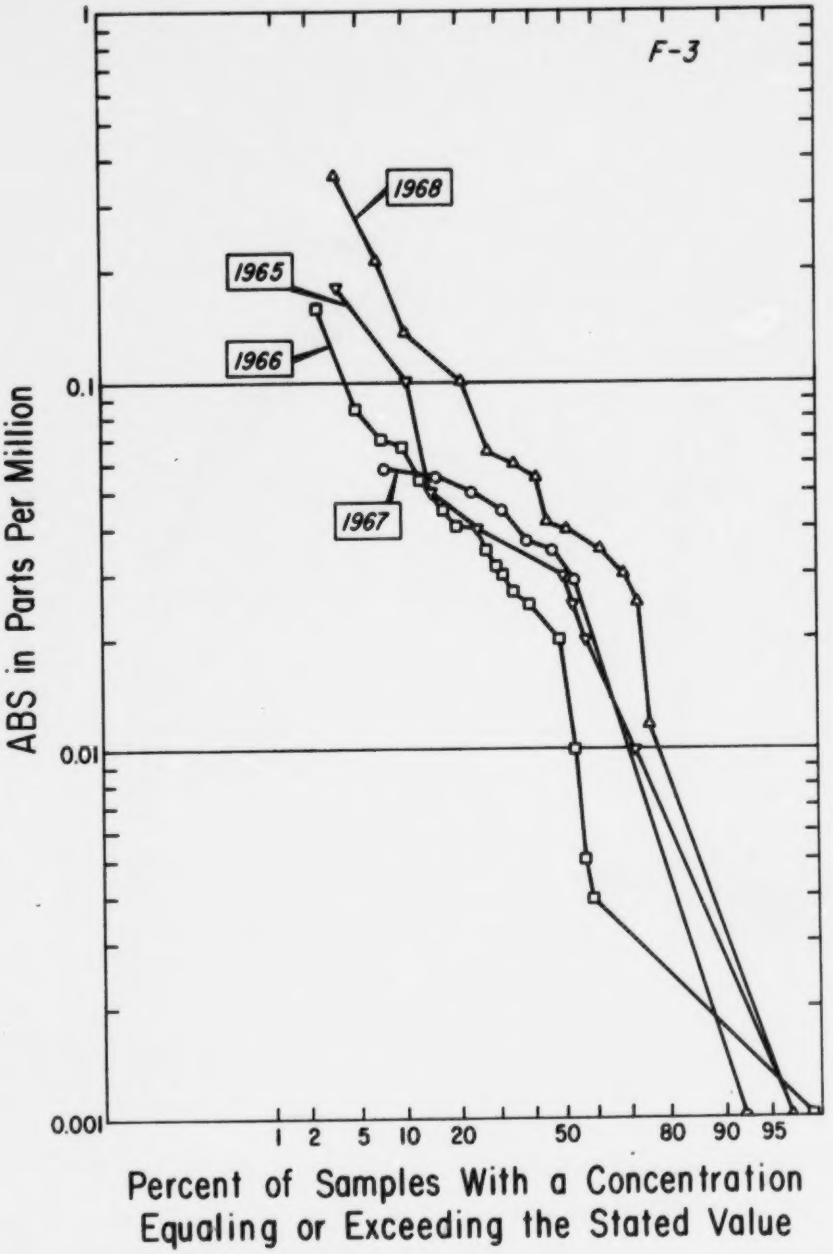

Figure 82. Percent of F-3 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values.

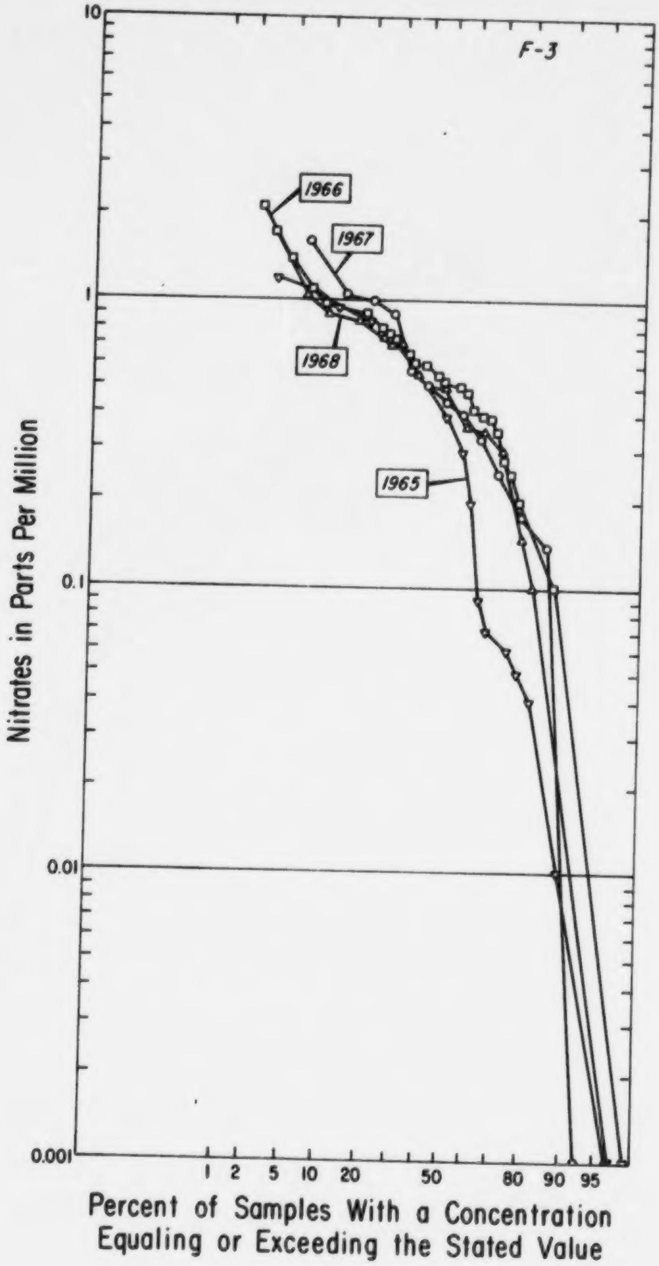

Figure 83. Percent of F-3 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values.

man's activities. Concentrations equalled or exceeded by 80% of the values ranged from a low of 0.04 in 1965 to a high of 0.18 ppm in 1966. The median values ranged from a low of 0.4 ppm in 1965 to 0.52 in 1966. The values equalled or exceeded by 20% of the values ranged from 0.80 to 1.0 ppm.

Chloride values equalled or exceeded by 80% of the values were less than .02 ppm for 1965, 1966, and 1967, and rose to .35 ppm by 1968 (Fig. 84). Median values were 0.14 ppm in 1965, 0.35 in 1966, 0.30 ppm in 1967 and 1.5 ppm in 1968. Chloride values equalled or exceeded by 20% of the values were 0.55 in 1965, 0.85 in 1966, 0.75 in 1967 and 3.0 ppm in 1968.

At best these reflect minor changes in quality and the concentrations are far below 250 mg Cl/1, the U. S. Public Health Service recommended limit for potable water.

Monitoring well F-4 provided water samples on a regular basis until it went dry in 1968. Chloride concentrations increased in 1967 over values observed in 1964-66 and is an indication that reclaimed effluent must have migrated to this point nearly five years after irrigation had started. Groundwater flow from the vicinity of part of the irrigated areas was toward F-4 and Big Hollow prior to the start of irrigation. A groundwater mound beneath the Agronomy-Forestry area continued to favor flow in this direction after irrigation began. The recharge area for this mound is partly wooded and partly under agricultural development. However, chloride increases must reflect recharge of reclaimed effluent because no other special changes were noted in the land use in the area that could account for the increases in chlorides noted.

The chloride values for F-4 equalled or exceeded by 80% of the values were between 0.01 and 0.02, 1964 through 1966, and increased to 0.06 ppm in 1967 (Fig. 85). The median values were around 0.05 in 1964, .02 in 1965, 0.22 in 1966 and increased to 1.2 ppm in 1967. The values equalled or exceeded by 20% of the values were 0.6 ppm in 1964, 0.14 in 1965, 0.47 in 1966 and 2.8 ppm in 1967. These values are of no consequence for drinking water quality.

NO_3-N values for F-4 were higher in 1964 than 1965 and 1966 and slightly higher than in 1967 (Fig. 86).

The value equalled or exceeded by 80% of the NO_3-N values for F-4 was 0.32 ppm in 1964, less than 0.04 in 1965 and 1966 and 0.22 ppm in 1967. The median values were 0.52 in 1964, less than 0.01 in 1965 and 1966, and 0.35 in 1967. The NO_3-N value equalled or exceeded by 20% of the values was 0.8 in 1964, 0.3 in 1965, 0.2 in 1966, and back to 0.6 ppm in 1967. None of the values are much above background levels for typical groundwaters in the region.

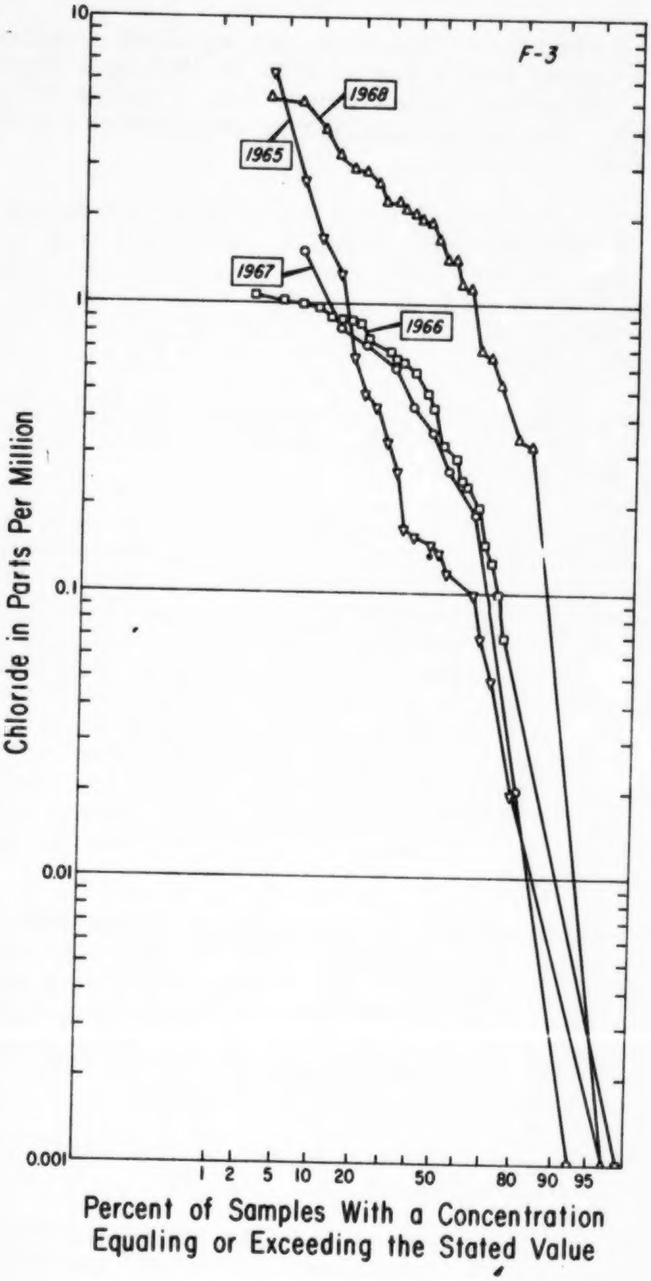

Figure 84. Percent of F-3 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values.

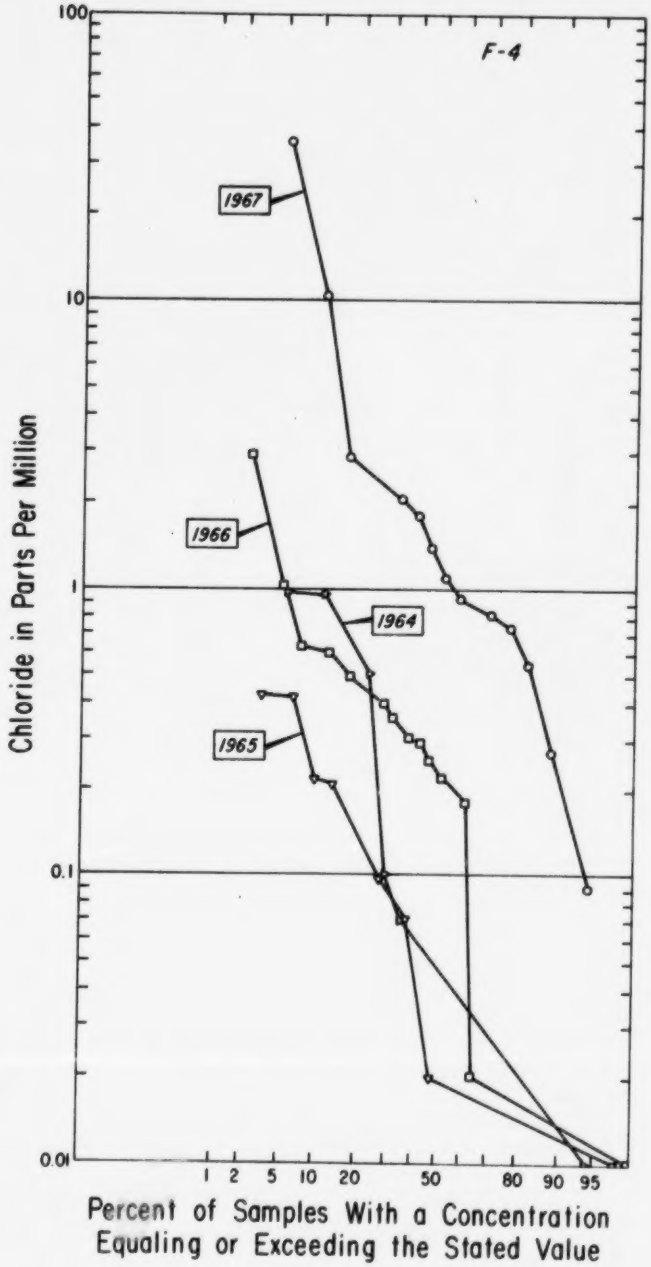

Figure 85. Percent of F-4 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values.

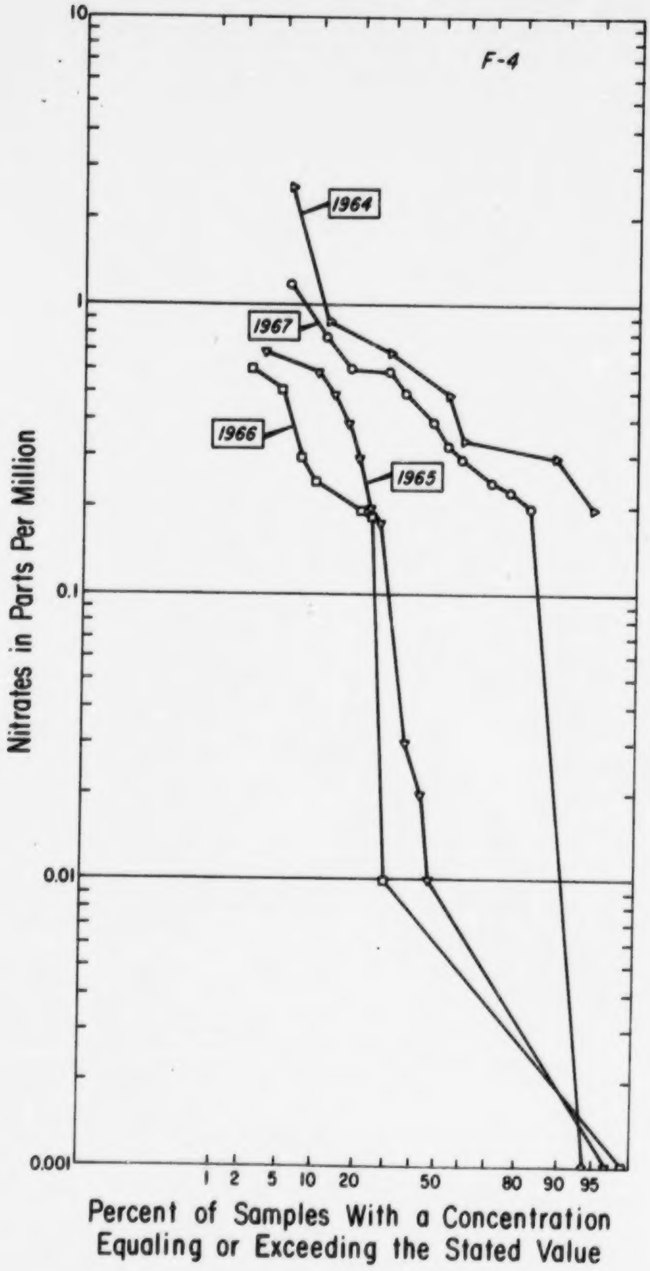

Figure 86. Percent of F-4 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values.

ABS values for F-4 do not exceed background levels (Fig. 87). Median values cluster around .03 ppm or less.

Phosphorus values in F-4 also remained at background levels (Fig. 88). The median values were less than 0.01 ppm in 1964 and 1965, and less than .02 in 1966 and 1967. The value equalled or exceeded by 20% of the values was less than 0.03 ppm in 1964 and 1965, and less than 0.05 ppm in 1966 and 1967.

Chemical data from monitoring well F-5 shows a pattern somewhat similar to UN-14. This well is closest to the Agronomy-Forestry irrigation site and should reflect the quality of reclaimed effluent with only limited dilution. It also is located in the direction of concentrated groundwater flow from irrigated areas to UN-14.

Chloride increased by 1966 and 1967 over 1965 levels followed by a further increase in 1968 (Fig. 89). The well was not available as a monitoring point prior to 1965 but 1965 chloride values are similar to those obtained from other wells at control sites. Reclaimed effluent must have reached F-5 by 1966 following the expansion of the project in 1965 to include the nearby reed canarygrass and new red pine disposal sites.

The median chloride value in F-5 was 0.12 ppm in 1965, 1.1 in 1966, 0.62 in 1967 and 7.0 ppm in 1968 (Fig. 89). The value equalled or exceeded by 20% of the values never exceeded 1.5 ppm during 1965, 1966 and 1967 but increased to 8.1 ppm in 1968.

Unlike the chloride values, the NO_3-N values in F-5 remained at background levels (Fig. 90). The value equalled or exceeded by 80% of the values was approximately 0.35 ppm for 1965 and 1968. The median values for these same two years was about 0.55 ppm and the value equalled or exceeded by 20 percent of the values was approximately 0.80 ppm. These results are significant in view of the proximity of F-5 to the irrigation sites and its location on a fracture trace intersection which should tend to channel groundwater flow to UN-14 and other production wells in the University well field.

Phosphorus and ABS data for F-5 also are in the background range (Fig. 91 and 92). The median values all were below 0.05 ppm of P and 0.07 ppm of ABS.

Because of the position of F-5 on a groundwater mound maintained by recharge from reclaimed effluent (Figs. 4 and 5) and with no other land uses that could account for the chloride values observed in F-5, it must be concluded that changes in chloride noted are related to reclaimed effluent. A similar statement with the same degree of confidence cannot be made for UN-14, and F-4. These monitoring points can show chloride and nitrate changes derived from adjacent land uses which cannot be separated from a possible wastewater irrigation source.

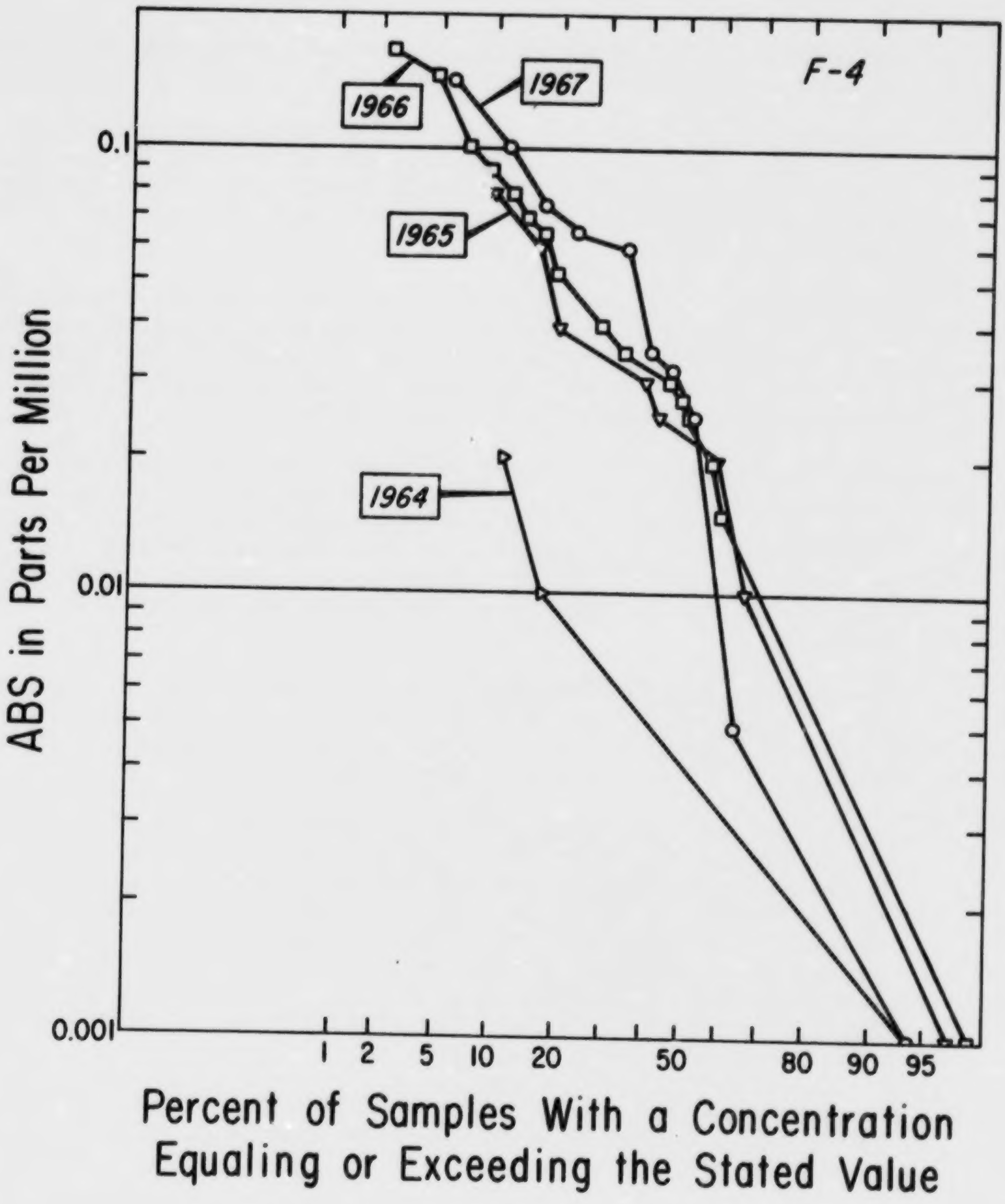

Figure 87. Percent of F-4 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values.

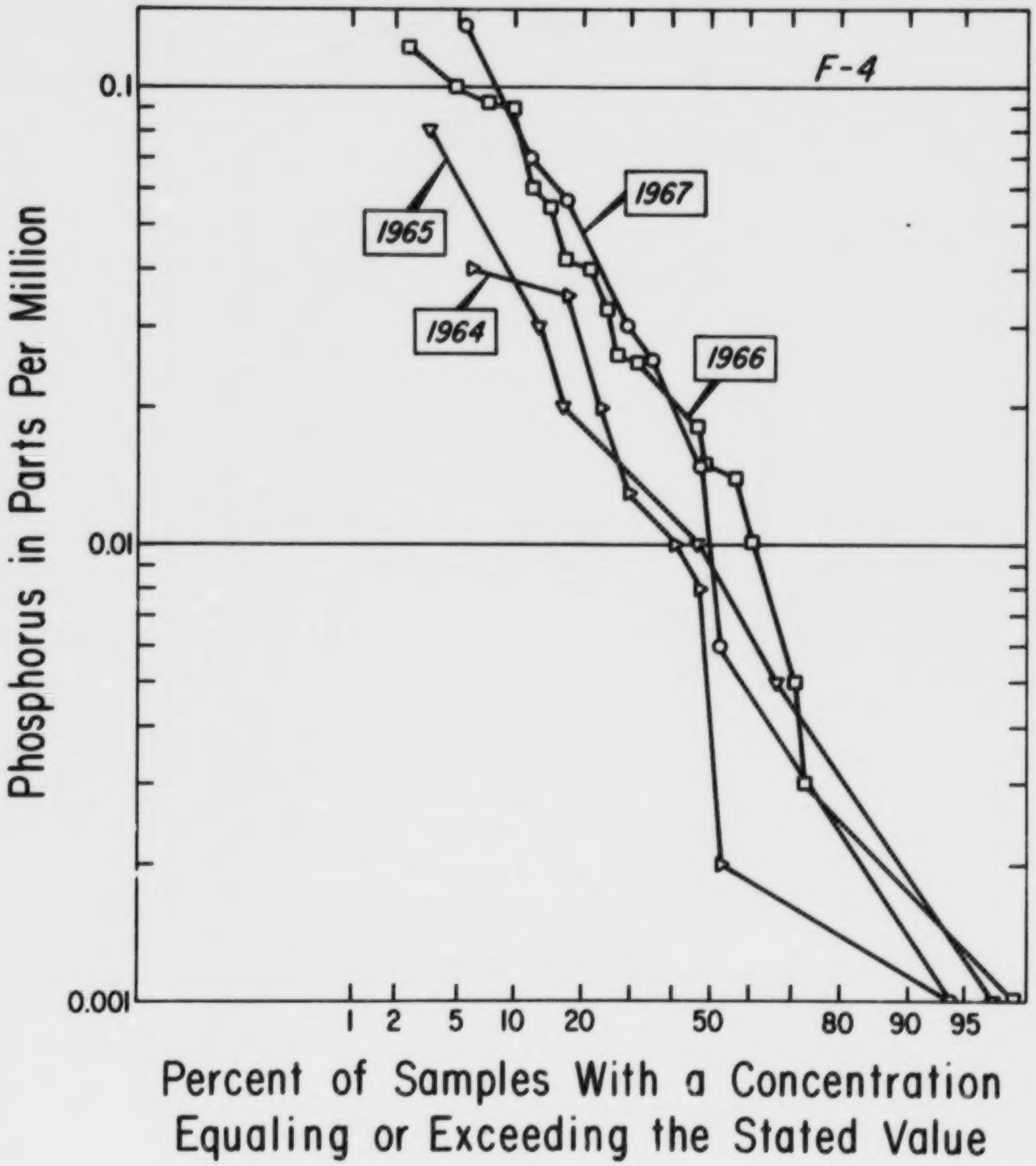

Figure 88. Percent of F-4 Deep Well Samples with P Concentrations Equalling or Exceeding Stated Values.

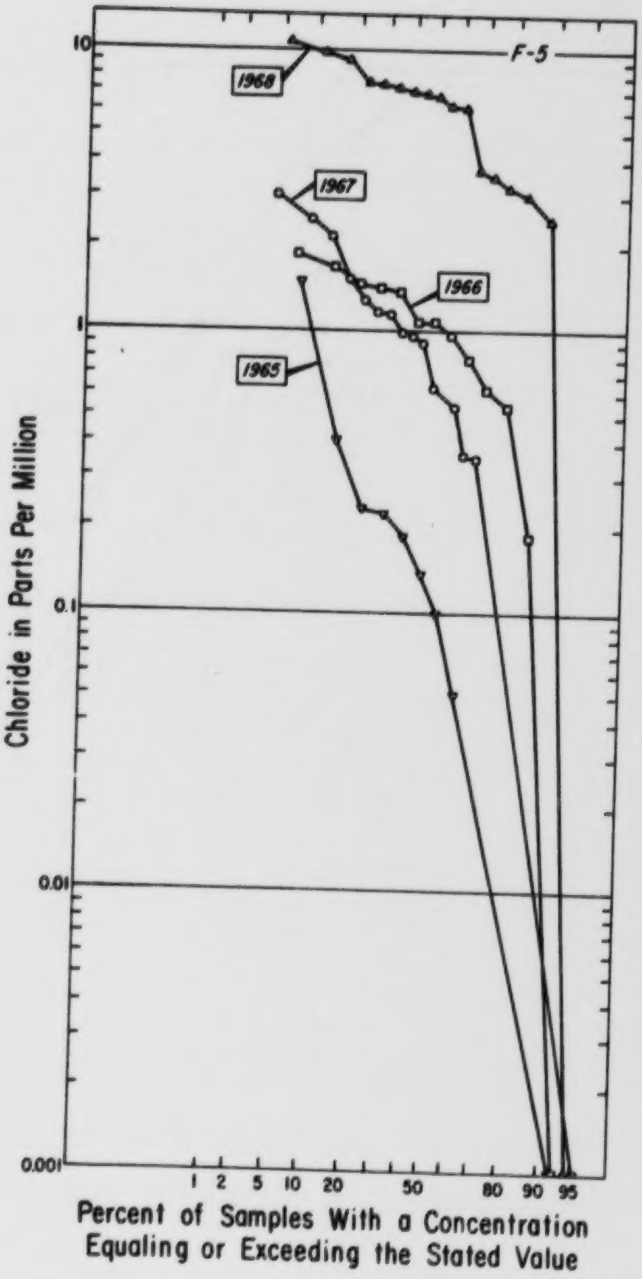

Figure 89. Percent of F-5 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values.

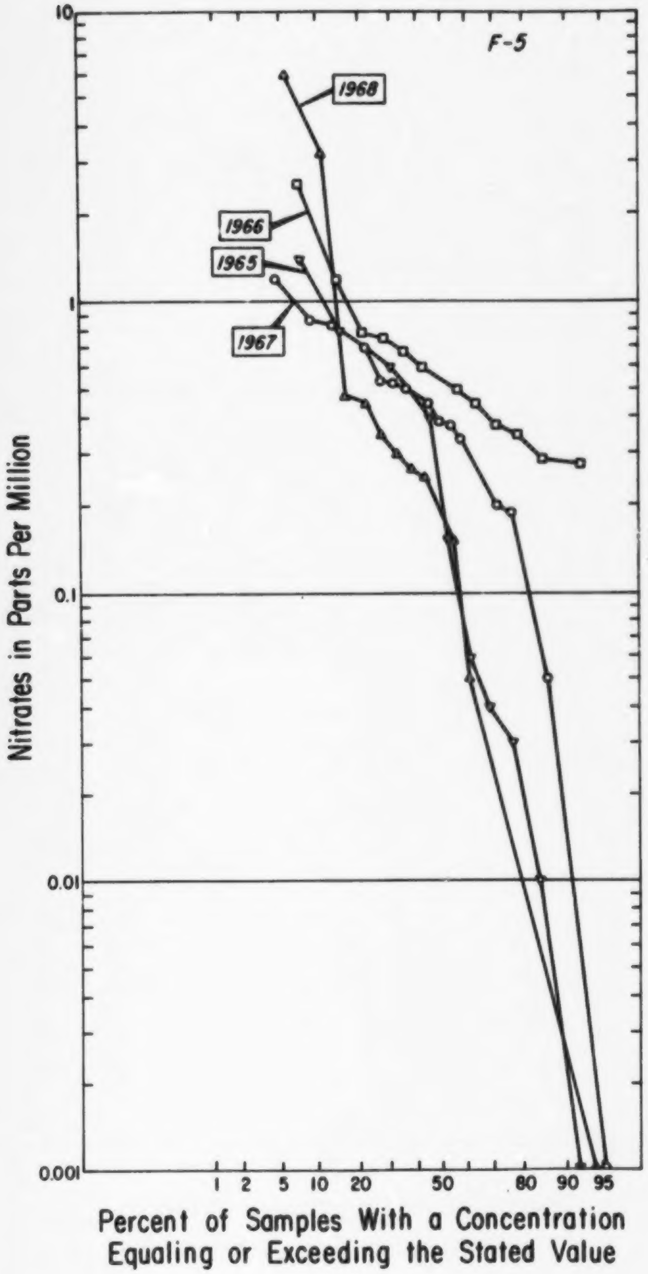

Figure 90. Percent of F-5 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values.

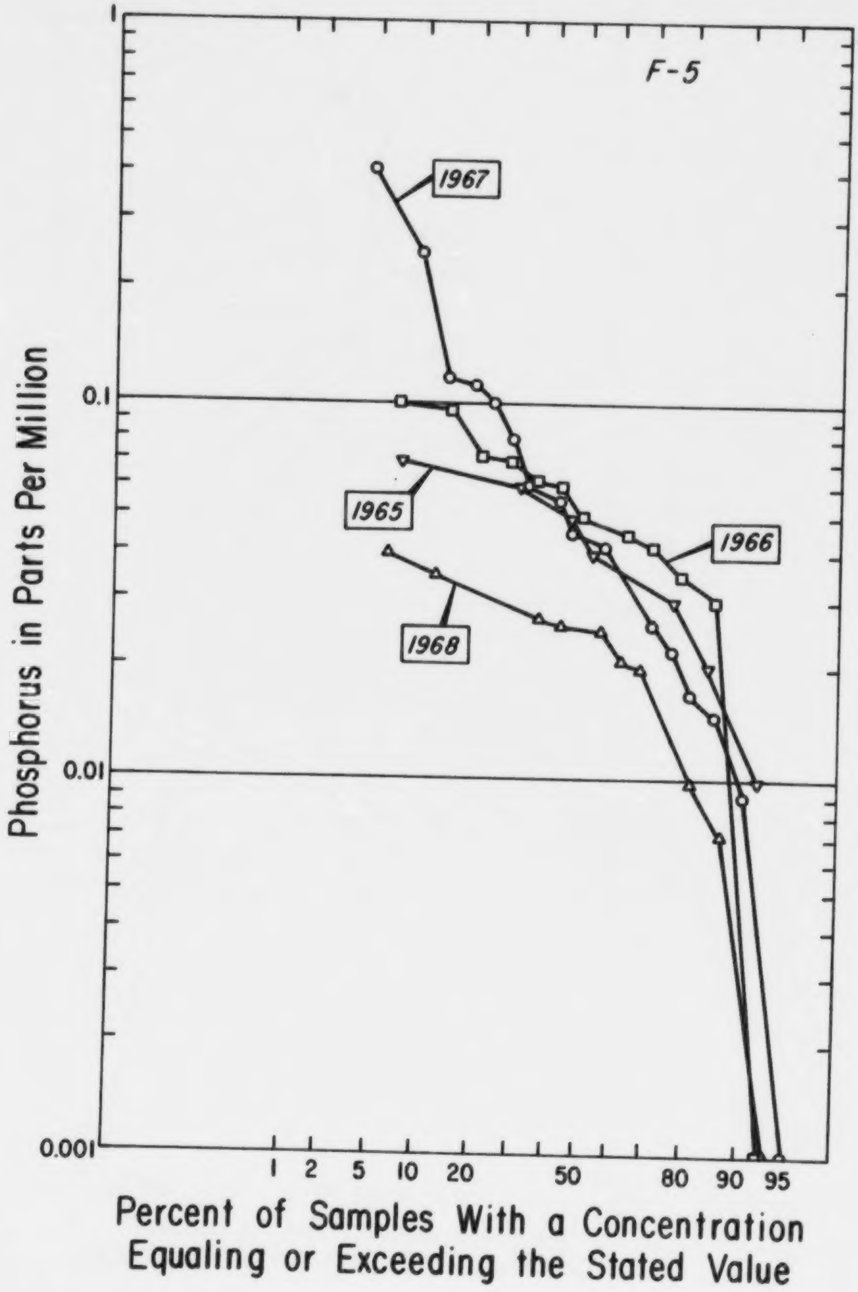

Figure 91. Percent of F-5 Deep Well Samples with P Concentrations Equalling or Exceeding Stated Values.

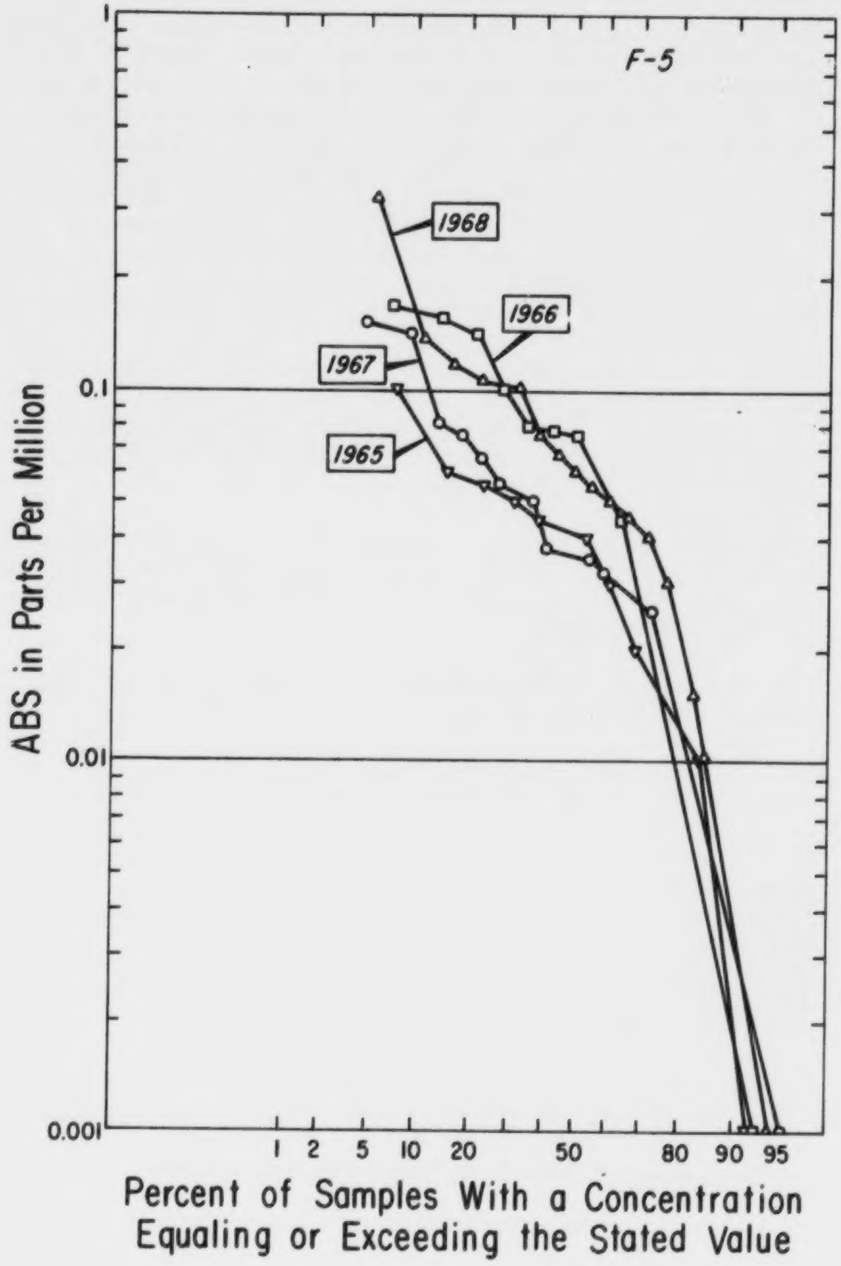

Figure 92. Percent of F-5 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values.

Monitoring well F-1 shows lower chloride values than F-5. Both wells are within a few feet of irrigated areas. However, F-1 is closest to Agronomic test plots that were irrigated only during April through November beginning in 1963. F-5 is immediately adjacent to the reed canarygrass plot that received 2 inches of effluent per week year-round starting in July, 1964. Two zones of fracture concentration channel reclaimed effluent to F-5 whereas F-1 was drilled within a block of dolomite and sandy dolomite strata bounded by more distant zones of fracture concentration. Hence F-1 should yield water of lower chloride content because the site receives less irrigation on an annual basis and dilution should occur during winter months.

The analysis of variance of the mean annual concentration of phosphorus in the UN wells showed a significant year effect only for UN-14 but only at the 10% level of significance and even then the last year, 1969, was not significantly different from the first year, 1962, the pre-test year. (Table 149)

With the F wells only in the case of F-1 was the year effect on mean annual phosphorus concentration significant (P = 0.01) but again the last year (1969) was not significantly different from the first year (1963). (Table 149)

The year effect on mean annual concentration of phosphorus was non-significant for any of the private wells (W-wells). (Table 149)

With respect to nitrate-nitrogen there was a highly significant year effect with two of the three UN wells (UN-14 and UN-24). These two wells happened to be closest to the effluent irrigated Agronomy-Forestry Area but are also located in a sandier soil area which is more intensively farmed than where the third well (UN-17) is located. The higher rainfall since 1967 may be pushing more nitrates out of the sandy soils surrounding UN-14 and UN-24. Of these two wells only in the case of UN-14 was the nitrate level significantly greater in the last two years, 1968 and 1969, than in the first two years, 1962 and 1963. (Table 150)

In the case of the F-wells only the F-1 well showed a highly significant year effect on nitrate concentration and even then the change in concentration cannot be attributed to effluent irrigation since the highest value occurred in the first year, 1963. (Table 150)

In the W-wells the year effect on nitrate concentration was significant (P = 0.01) in three of the four wells but there was no consistent time pattern which might be ascribed to effluent irrigation. (Table 150)

Although the year effect on mean annual chloride concentration was highly significant for the three UN wells, the four W-wells and two of the three F-wells the time pattern was not always consistent with continuing effluent irrigation. For example with the UN wells the chloride concentration in 1969 was not significantly different from the value in the first year of record. The same was true for F-3, W-3, W-5 and W-30. In the other two wells F-5 and W-7 although chloride concentration was greater in the last year than in the first year of record, the lowest concentration did not occur in the first year in W-7 and the highest concentration did not occur in the last year of record in F-5. (Table 151)

Table 149. Phosphorus in Monitoring Wells.

		Year								
Well No.	Distance[1]	1962	1963	1964	1965	1966	1967	1968	1969	Significance[2]
	feet	Mean annual concentration - mgP/liter								
UN-14	1300	0.010ab[3]	0.005a	0.002a	0.019ab	0.015ab	0.021ab	0.019ab	0.021b	†
UN-17	3300	0.009	0.004	0.008	0.018	0.018	0.028	0.042	0.016	N.S.
UN-24	2200	0.010	0.019	0.016	0.020	0.036	0.032	0.022	0.019	N.S.
F-1	100	--	0.020ab	0.009ab	0.053c	0.032b	0.011ab	0.001a	0.016ab	**
F-3	1200	--	--	--	0.009	0.016	0.015	0.016	0.017	N.S.
F-5	200	--	--	--	0.042	0.059	0.063	0.027	0.032	N.S.
G-3	0	0.018	--	--	0.006	--	0.028	0.029	0.019	N.S.
G-10	500	--	--	--	--	--	0.034	0.036	0.027	N.S.
W-3	5700	0.010	0.009	0.019	0.021	0.022	0.022	0.037	0.002	N.S.
W-5	5300	0.011	0.011	0.007	0.016	0.010	0.031	0.036	0.015	N.S.
W-7	2600	0.005	0.005	0.006	0.023	0.003	--	--	0.022	N.S.
W-30	5300	0.007	0.011	0.004	0.008	0.005	0.020	0.028	0.015	N.S.

---

[1] Approximate distance from sewage effluent application area.

[2] Significance of year effect: **, (P = 0.01); *, (P = 0.05); †, (P = 0.10); N.S. - not significant, (P > 0.10).

[3] Duncans separation of annual means at P = 0.05. Annual means having a common letter are not different.

Table 150. Nitrate-N in Monitoring Wells.

Well No.	Distance[1]	Year								Significance[2]
		1962	1963	1964	1965	1966	1967	1968	1969	
	feet	Mean annual concentration - mg NO_3-N/liter								
UN-14	1300	1.6ab[3]	1.9a	2.3abc	1.4a	1.8a	2.9bc	3.1c	4.0d	**
UN-17	3300	0.6	0.6	0.5	0.2	0.3	0.6	0.4	0.4	N.S.
UN-24	2200	0.6ab	0.6ab	0.3a	0.5a	1.2b	1.0b	0.9ab	1.3b	**
F-1	100	--	1.4c	0.7ab	0.4a	0.9bc	0.9bc	0.5ab	0.4a	**
F-3	1200	--	--	--	0.4	0.6	0.4	0.5	0.4	N.S.
F-5	200	--	--	--	0.4	0.6	0.4	0.8	0.3	N.S.
G-3	0	0.2ab	--	--	0.1a	--	3.6b	3.5b	2.8b	**
G-10	500	--	--	--	--	--	0.9b	0.3a	0.4a	*
W-3	5700	10.1c	9.2c	4.6ab	3.2a	5.0ab	7.6bc	10.2c	7.3abc	**
W-5	5300	5.3c	5.0bc	4.0abc	3.0a	3.2a	3.7ab	4.4abc	5.7c	**
W-7	2600	1.3ab	1.9b	1.3ab	0.7a	0.6a	--	--	--	**
W-30	5300	1.9	1.3	1.9	1.2	1.4	2.3	2.4	2.2	N.S.

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[1] Approximate distance from sewage effluent application area.

[2] Significance of year effect: **, ($P = 0.01$); *, ($P = 0.05$); †, ($P = 0.10$); N.S. - not significant, ($P > 0.10$).

[3] Duncans separation of annual means at $P = 0.05$. Annual means having a common letter are not different.

Table 151. Chloride in Monitoring Wells.

		Year								
Well No.	Distance[1]	1962	1963	1964	1965	1966	1967	1968	1969	Significance[2]
	feet	Mean annual concentration - mg Cl^-/liter								
UN-14	1300	2.3ab[3]	2.8ab	1.2a	0.6a	0.8a	1.3a	3.7b	3.5b	**
UN-17	3300	1.2ab	1.5ab	0.1a	0.0a	0.2a	0.4a	1.8b	1.4ab	**
UN-24	2200	--	--	0.1a	0.2a	0.8a	1.7b	0.8a	0.6a	**
F-1	100	--	1.1	0.4	0.4	0.3	0.4	0.7	0.5	N.S.
F-3	1200	--	--	--	0.5a	0.4a	1.0a	1.5b	0.6a	**
F-5	200	--	--	--	0.2a	1.0ab	1.2bc	7.2d	2.7c	**
G-3	0	1.8a	--	--	2.5a	--	10.7ab	14.4b	13.3b	**
G-10	500	--	--	--	--	--	11.1b	12.1b	1.8a	**
W-3	5700	13.3c	12.1c	3.2a	4.0a	6.1ab	10.3c	10.2bc	8.4abc	**
W-5	5300	4.6d	4.8d	4.0cd	3.3bcd	0.6a	1.5ab	1.9abc	4.9d	**
W-7	2600	1.7b	1.8b	0.1a	3.4b	6.7c	--	--	--	**
W-30	5300	2.4b	2.4b	0.9a	0.7a	1.2ab	1.9ab	1.3ab	3.0b	**

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[1] Approximate distance from sewage effluent application area.

[2] Significance of year effect: **, ($P = 0.01$); *, ($P = 0.05$); †, ($P = 0.10$); N.S. - not significant, ($P > 0.10$).

[3] Duncans separation of annual means at $P = 0.05$. Annual means having a common letter are not different.

Gamelands Area

Introduction. Irrigation began in the Gamelands in November 1964 at one site at a 4-inch rate and at two sites at a 6-inch application rate. This continued until April 1965 when irrigation of the 6-inch sites was changed to 4 inches per week. In August, 1965 all application at the Gamelands site was terminated until November. At that time the irrigation program was changed to a November-March period and two additional sites, one a hay field and the other a forest area were started with irrigation at two inches per week on a year-round basis. The hay field site was terminated in Oct., 1969.

The soils have a higher sand content with occasional beds of relatively clean sand being not uncommon. These beds may vary from 1 to 5 feet in thickness and characteristically are interbedded with silt and clay beds that make the deposits highly anisotropic with respect to permeability. Slopes are gentle as a rule but, locally, wastewater is applied where slopes exceed 6 percent. The sandy and stratified nature of the soil results in some lateral flow of perched groundwater.

Monitoring Facilities

Deep Wells. Deep groundwater monitoring wells were drilled during the initial site selection and evaluation study conducted in 1962. These include G-1, 2, 3, and 6. Groundwater levels rapidly declined in the region at the start of the drought in 1961. G1, 2, 3 and 6 were dry within less than a year and failed as monitoring wells. G-3 was successfully deepened after going dry and was a rather reliable monitoring well but too small in diameter to provide water level data after installation of a pump. The other drilled wells, G1, 2 and 6 which had a final diameter of either 3 or 2 1/2 inches were not deepened because of their small diameter, or because caving conditions and or flowing sand were encountered.

G-3 is located on a single zone of fracture concentration at the center and near the head of a dry underdrained karst valley. Six inches of effluent were applied at weekly intervals to both valley walls the first year November through August and four inches on a November through April basis during subsequent years. A 4-inch application rate was used at the head of the valley as well.

Sidehill seepage along the lower segments of the valley and lower reaches of the valley walls was rather abundant the first winter in response to the 6-inch per week application rate. Runoff flowed past G-3 nearly on a daily basis the first winter. In subsequent years, after the irrigation rate had been cut to 4-inches per week, November-April, surface seepage was greatly reduced but still noticeable.

Subsequently G-12 was drilled in 1964 on a single zone of fracture concentration to a final diameter of 6-inches and a depth of 300 feet. At that point a bit was lost which precluded drilling any deeper. The well had to be doubly cased to the total depth drilled to control flowing sand. This well also went dry and failed to yield water samples within less than a year of being drilled and remains inoperative to present. It is located on the center line of the same valley but up slope from G-3. The well did help to define the deep groundwater low that underlies the Gamelands irrigation site.

G-10 was completed in 1966 at a 6-inch diameter. The well is doubly cased, located on a zone of fracture concentration and down valley from G-3. More than 80 feet of residual soil was encountered at the drill site and 100 or more feet of unsaturated dolomite or sandy dolomite bedrock.

Runoff from the irrigation site rarely extended beyond G-10. Rather, water was captured in a diffuse manner by sandy soil with a forest cover up valley from G-10.

A 2-inch per week open field irrigation site was operated from Nov., 1965 to Oct., 1969 along one valley wall up slope to the south of G-10.

Despite the high topographic position of the Gameland irrigation area, G-3 and 10 are both located in a groundwater low along which regional groundwater flow is concentrated (Fig. 5). Their strategic location along the center of a valley along which overland flow is concentrated, position with respect to irrigated areas, and to zones of fracture concentration that should channel reclaimed effluent to the monitoring wells make it inevitable that both wells intercept effluent within the groundwater reservoir before it leaves the Gamelands test area.

Water samples were bailed from G-3 the first year and were pumped from G-3 and G-10 in subsequent years using small diameter piston pumps. The pumps insured that more representative samples of groundwater were obtained than if hand bailing methods were used.

Trench Lysimeter. A second sampling facility at the Gamelands was a 17-foot deep trench lysimeter which was placed near the base of a valley wall mid way along the irrigation lines. No water samples were collected prior to irrigation because the soil was too dry. Immediately following the second week of irrigation, or after 12-inches of effluent had been applied early in November, sidehill seepage became excessive and the deep trench was flooded to ground level. Water levels were controlled in the lysimeter pit using an electrical submergible pump and portable generator for part of 1965 and early 1966. The pit remained flooded to various levels for more than a month during the winter and early spring of 1966 and did not completely dry out until irrigation was stopped in August 1966. After installing a floor drain and cutting back on the application level the lysimeter pit never flooded again and continues to provide water samples to the present.

Suction-Pressure Lysimeters. A network of stacked suction-pressure lysimeters was installed at seven sites to replace the faulty sandpoint wells which failed to yield soil water samples the first year, 1964-65. Two each of these were located in the 6-inch and 4-inch per week winter irrigated area one midway down slope and one at the bottom of a slope in a region of noticeable runoff. Three other stacks of suction-pressure lysimeters were placed in two 2-inch per week year-round irrigated areas, one in an open field site and two in a forested site.

Suction pressure lysimeters were stacked two or more to a drill hole (6) at approximately 5 foot intervals from depths of 6 to 26 feet. These have provided rather reliable samples until 1970 except during dry months in the non-irrigation period on the winter irrigation sites.

Water Quality

Deep Wells Quality. Figures 93, 94 and 95 display the percent of samples that equalled or exceeded stated Cl, NO_3-N, and apparent ABS values for G-3. Chloride levels were in the background range during 1965 and 1966 and began to show an increase by 1967 indicating that approximately five years were required for the reclaimed effluent to appear in local groundwater in sufficient volume to be detected. Chloride concentrations changed from a median of 2.7 ppm in 1965, and 2.0 ppm in 1966 to 12 ppm in 1967 and 1968. Eighty percent of the chloride values equalled or exceeded 2 ppm in 1965, 1.8 ppm in 1966, 11 ppm in 1967 and 7.0 ppm in 1968. Only 20% of the chloride concentrations equalled or exceeded 14 ppm in 1967 and 23 ppm in 1968 and were well within acceptable potable water limits during each sampling.

1967 and 1968 chloride data for G-10 show similar results with a median value of 11 ppm for 1967 and 13 ppm for 1968. Eighty percent of the chloride values in G-10 equalled or exceeded 12.5 ppm in 1967, and 15 ppm in 1968. These values were slightly lower than for G-3 because G-3 is more centrally located within irrigated areas. Groundwater in the vicinity of G-3 should receive less dilution and show less influence of dispersion than would be true near G-10.

Nitrate-nitrogen concentrations for G-3 also showed an increase by the fifth year of irrigation (Fig. 94) and continue to remain above initial background levels to the present. This well should have felt the full brunt of the excessive irrigation amount of 6 inches of effluent per week the first year because sidehill seepage was concentrated on both valley walls near G-3. Surface runoff has continued to occur along the center of the valley near G-3 each winter and approaches 5 to more than 30 gpm for short periods of time before infiltrating further down the valley floor.

The median nitrate-nitrogen value was as low as 0.52 ppm in 1965 and 0.54 ppm in 1966, which can be considered as background. These values

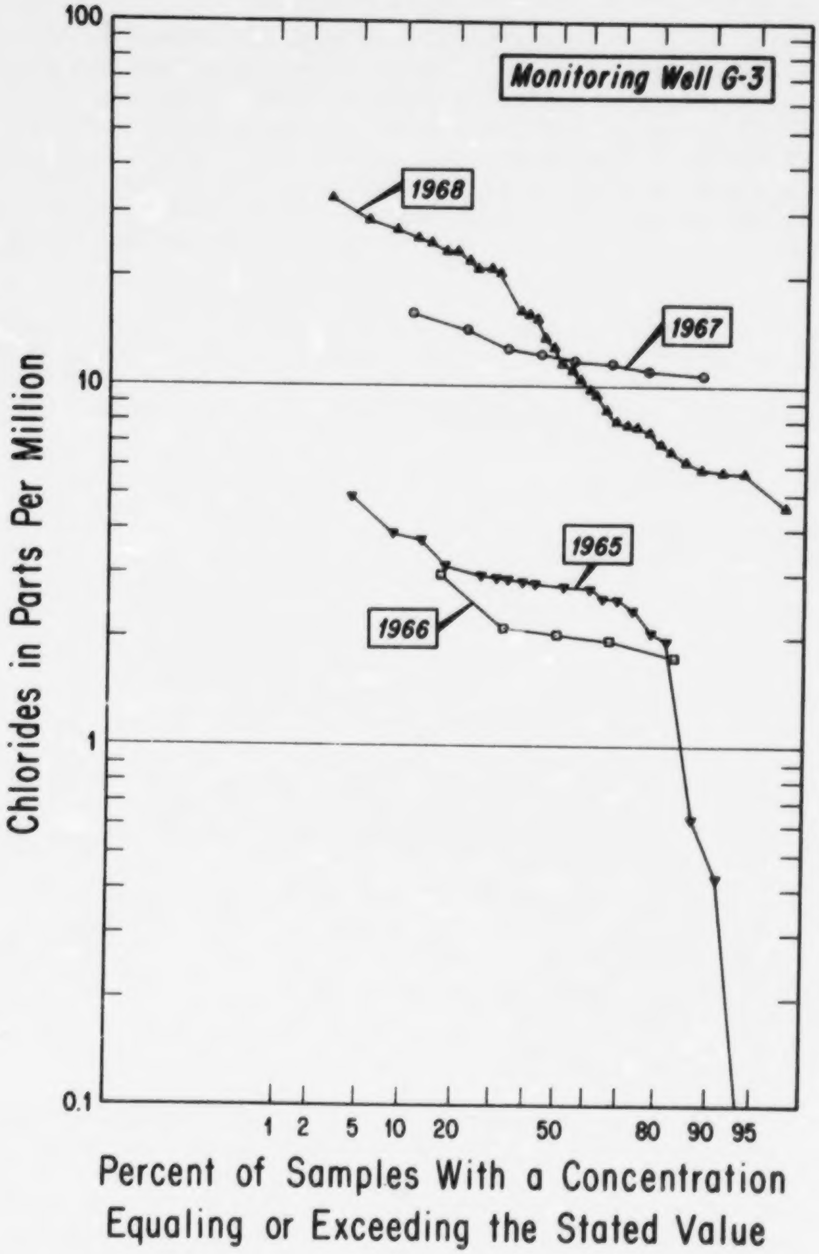

Figure 93. Percent of G-3 Deep Well Samples with Chloride Concentrations Equalling or Exceeding Stated Values.

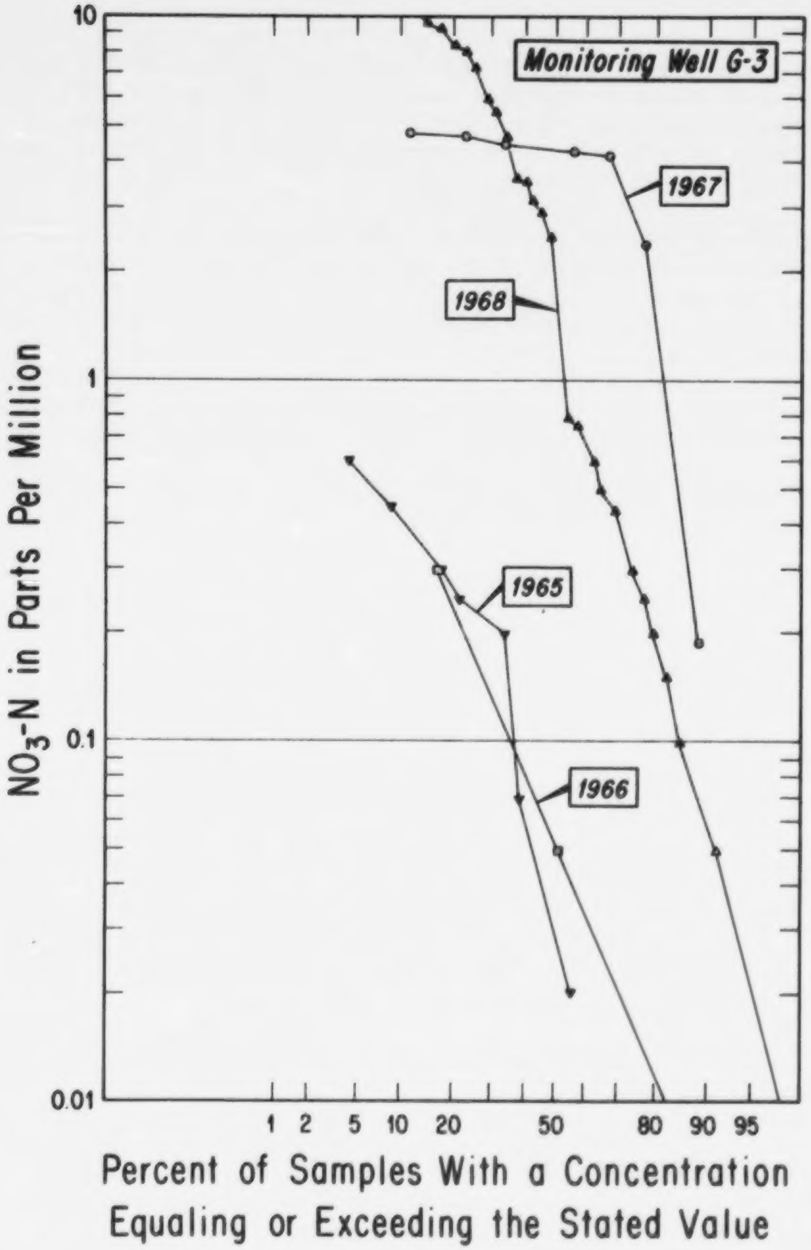

Figure 94. Percent of G-3 Deep Well Samples with NO_3-N Concentrations Equalling or Exceeding Stated Values.

increased to 4.4 ppm in 1967 and then dropped to 1.8 ppm in 1968. The slight reduction in 1968 compared to 1967 may reflect slow but increased dilution of groundwater related to increased precipitation in 1967 and 1968 and the decrease in application amounts following the first year of irrigation.

Compared to 1965 and 1966 values there can be little doubt that nitrate increases were related to the irrigation project because flow of groundwater within the regional groundwater low located below the Gamelands site is positioned largely beneath forested areas and abandoned farm land. The general lack or limited area of agricultural lands in the region of recharge rules out agricultural activity as a source of nitrates. Also few homes are present within the recharge area, hence septic tanks were not an important source of nitrates.

Unimportant changes in apparent ABS and phosphorus were noted in G-3 and G-10 (Fig. 95) for the period of available record.

The median ABS values in G-3 were 0.1 ppm in 1965, .04 ppm in 1966, .07 in 1967, and 0.1 ppm in 1968. These are within the background range. Similarly, phosphorus concentrations remained low and within the background range. The median values were less than .01 ppm in 1965 and 1966, 0.04 ppm in 1967 and 0.02 ppm in 1968. Similar and insignificant differences in ABS and phosphorus were noted for G-10 during 1967, 1968 and 1969.

The year effects for phosphorus, nitrate-nitrogen and chloride G-3 and G-10 are shown in Tables 149-151. For phosphorus, the year effect was not significant for both wells. With respect to NO_3-N the year effect was highly significant ($P = 0.01$) for G-3 but only significant ($P = 0.05$) for G-10. The NO_3-N concentrations in 1968 and 1969 were both significantly less than in 1967 but not significantly different from each other. This was probably a reflection of the decreased effluent loading which began in Nov., 1965.

The chloride data for G-3 and G-10 show the strongest year effects, being highly significant ($P = 0.01$) for both wells. In G-3 the chloride levels appear to have peaked out at less than 15 mg Cl per liter although the mean annual effluent concentration has remained fairly constant in the range of 40-50 mg Cl per liter. On the other hand in G-10, which is more remote from the irrigated area, the chloride concentration has decreased substantially from 1968 to 1969, dropping from 12.1 to 1.8 mg Cl/1. This drop is probably related to the lower irrigation load on the hay field adjacent to G-10 in 1968 combined with the earlier decreased load on the area surrounding G-3 which lies up-slope from G-10.

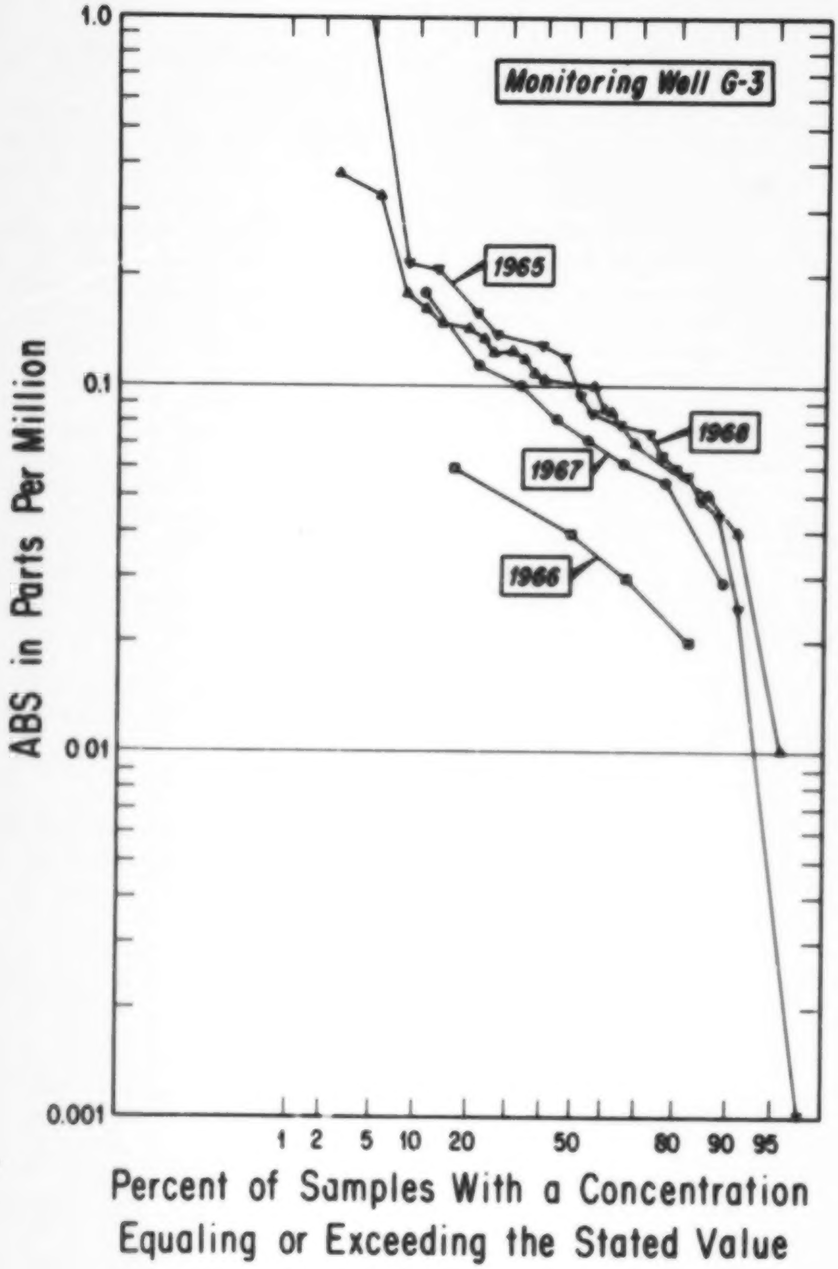

Figure 95. Percent of G-3 Deep Well Samples with ABS Concentrations Equalling or Exceeding Stated Values.

Trench Lysimeter Quality. Trench lysimeter data reveal that the 6-inch application rate the first year caused the chloride concentration to build up almost immediately after irrigation began in Nov, 1964. Table 152 and Figures 96-98 show the 20%, 50% and 80% values equalled or exceeded for 1965 through 1968 for the 5, 10 and 14 foot depths. Samples were collected at 1-foot intervals to 17 feet but all data are not shown to avoid repetition. It may be seen that the chloride concentrations were lowest in 1965 at all depths and that these increased by approximately 10 ppm in 1966. No background values for chloride were obtained from the trench lysimeter because no soil-water samples were obtained until after 12-inches of effluent were applied. However in a nearby control area chloride values in pan and section lysimeters rarely exceeded 3mg/1. It may be seen that the 14-foot deep samples show slightly higher chloride values than the 10 foot sampling depth. Lateral flow was particularly pronounced around the 14-foot depth. Water frequently continued to flow down slope into the sample pit at this depth after flow ceased at shallower sampling points. Water quality variations at this depth might be expected to be related to recharge up slope and prolonged lateral flow more so than from vertical percolation immediately above the pan lysimeters.

Table 153 and Figures 99-101 show the nitrate-nitrogen values equalled or exceeded by 20%, 50% and 80% of the samples at 5, 10 and 14 feet for 1965 through 1968.

Table 152. Chloride Concentrations Equalled or Exceeded by 20%, 50%, and 80% of the Values for 5, 10, and 14 foot Depths in the Gameland's Trench Lysimeter (SGL).

	Values Equalled or Exceeded by Various Proportions of Values											
	1965			1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft	mg Cl$^-$ per liter											
5	46	43	40	56	52	47	62	54	50	60	50	41
10	44	39	30	55	49	46	58	51	46	54	42	37
14	44	42	38	57	51	46	-	-	-	55	43	39

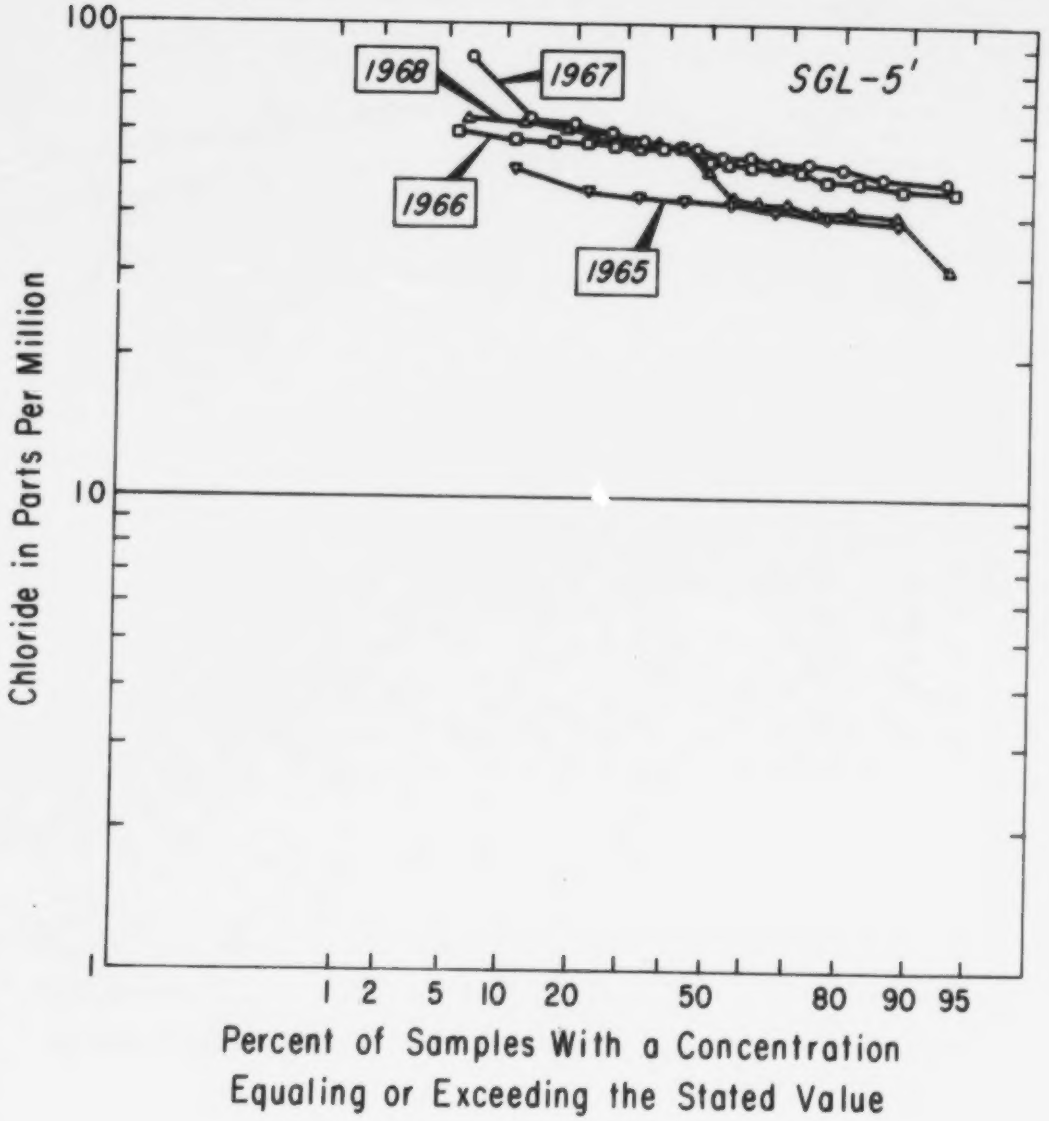

Figure 96. Percent of Deep Trench Lysimeter (SGL) Samples at the Five-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values.

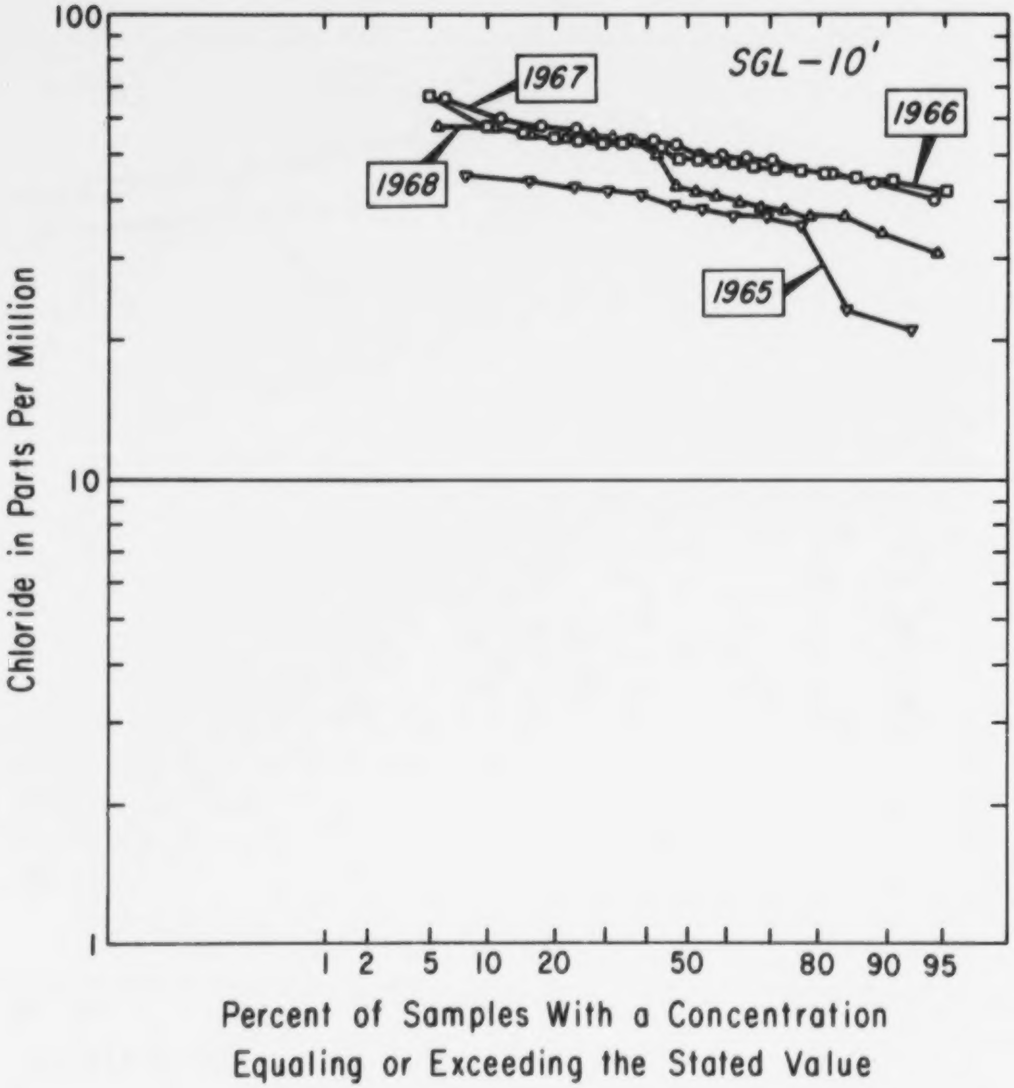

Figure 97. Percent of Deep Trench Lysimeter (SGL) Samples at the Ten-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values.

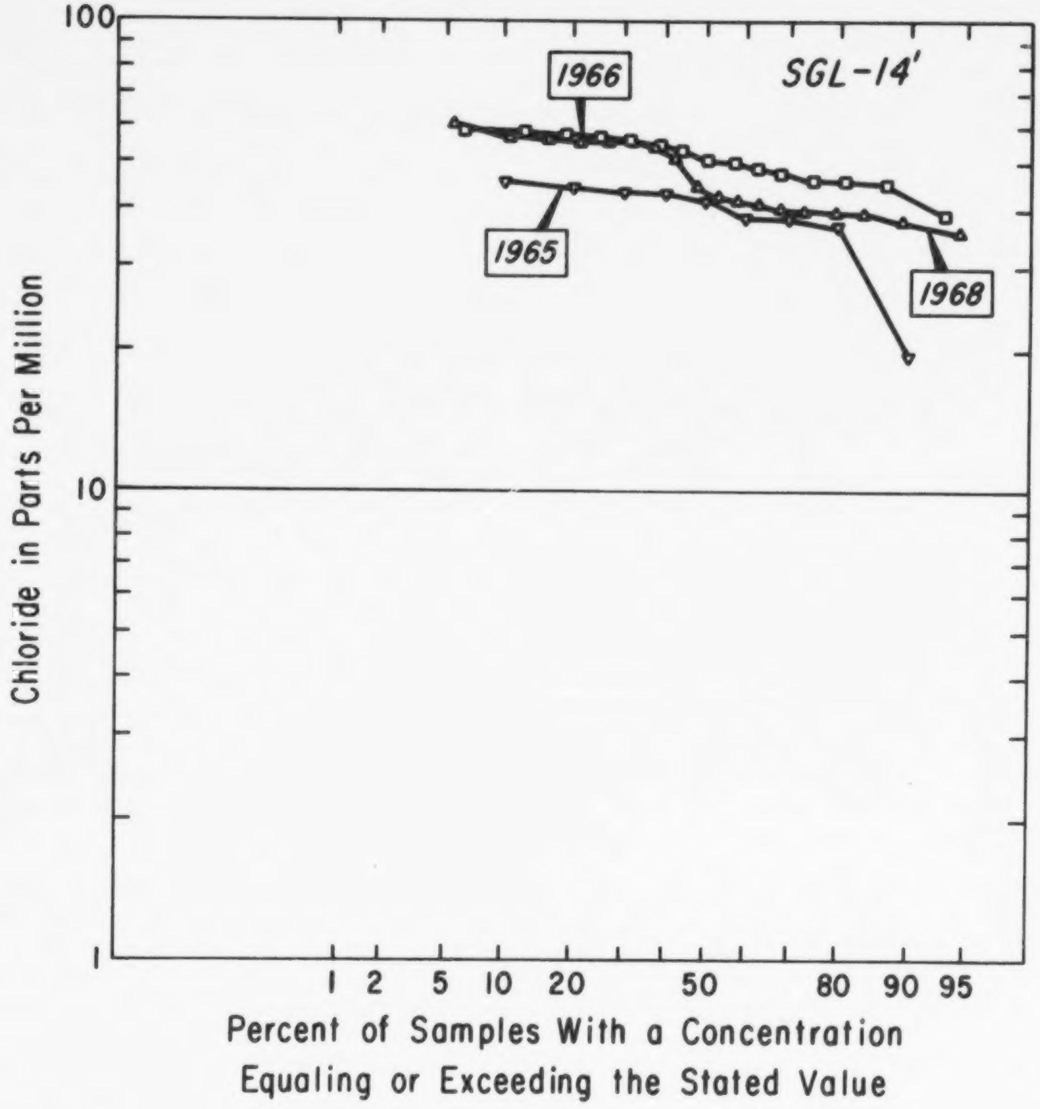

Figure 98. Percent of Deep Trench Lysimeter (SGL) Samples at the 14-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values.

Table 153. Nitrate-Nitrogen Concentrations Equalled or Exceeded by 20%, 50%, and 80% of the Values for 5, 10, and 14 foot Depths in the Gameland's Trench Lysimeter (SGL).

	Values Equalled or Exceeded by Various Proportions of Values											
	1965			1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft	mg NO_3-N per liter											
5	6.8	3.8	2.8	24	20	13	28	25	21	24	19	17
10	14.0	7.0	2.5	31	20	16	30	22	16	28	23	20
14	14.0	10.0	3.8	25	20	17	-	-	-	29	22	19

Nitrates like the chlorides moved rapidly and deeply through the soil in response to the 6-inch per week overload. The median (50%) values increased strongly with depth in 1965, just reaching the U.S.P.H.S. potable water limit of 10 mg NO_3-N at 14 feet. However in 1966, 1967 and 1968 the median values approached a constant value of approximately 20 mg NO_3-N at all depths even though the effluent load was cut to 4 inches per week and applied only during the Nov-March period. The decreased biological activity of both trees and microbes during the cold part of the year probably contributed to the greater breakthrough of nitrate.

Despite the overload of effluent in 1964-65 phosphorus concentrations remained low at all depths indicating the high degree of adsorption and renovation that can be achieved for this constituent even on a sandy soil. Values were all in the background range in 1965 and 1966 (Table 154 and Figures 102, 103, and 104) and showed a slight increase at the 10-foot depth in 1967 and at the 10 and 14 foot depth in 1968. These slight increases may reflect a slight breakthrough at these depths because of the prolonged lateral flow from up slope. The median values in 1968 after four years of heavy irrigation were 0.01 at the 5-foot depth, 0.14 at the 10-foot depth, and 0.12 at the 14-foot depth.

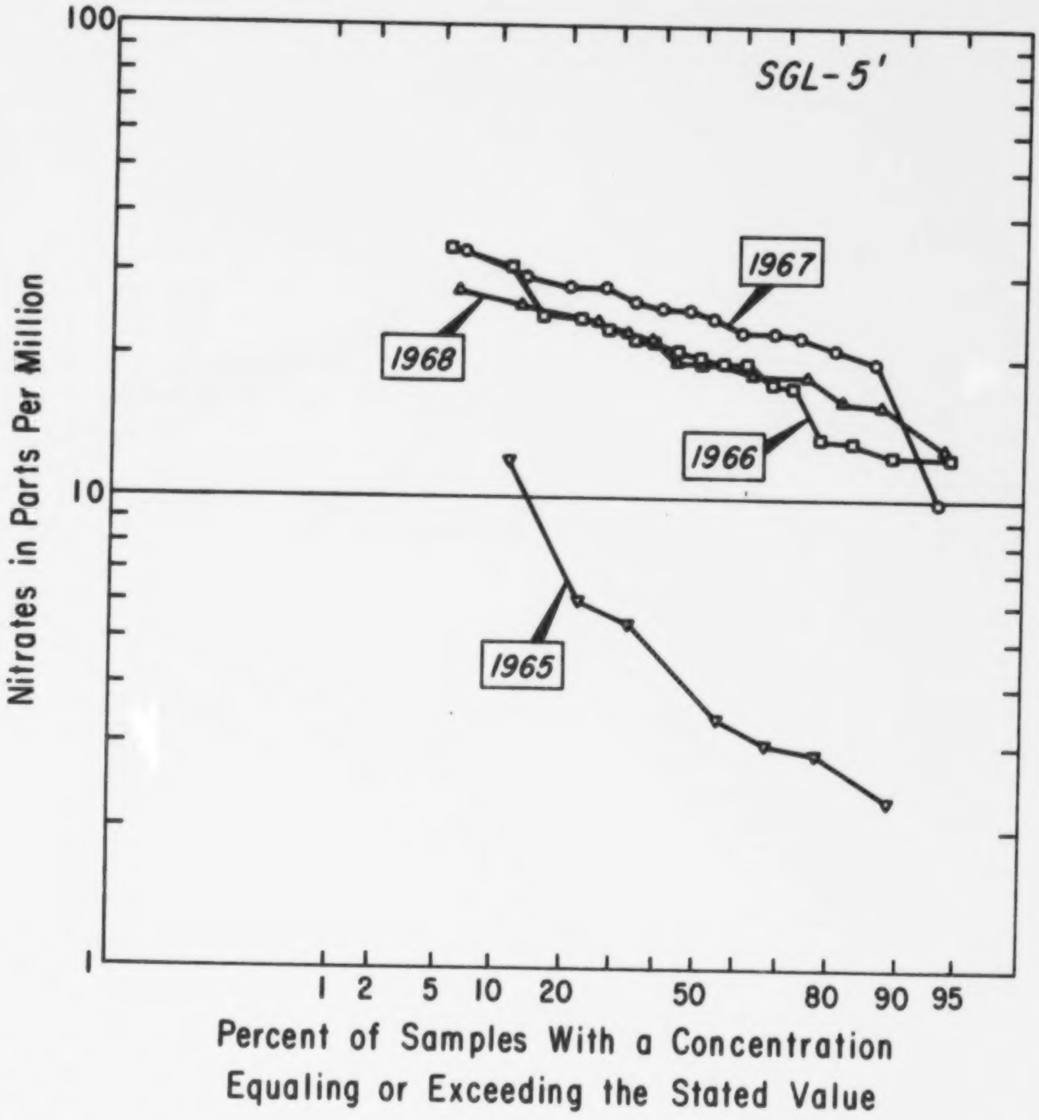

Figure 99. Percent of Deep Trench Lysimeter (SGL) Samples at the Five-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values.

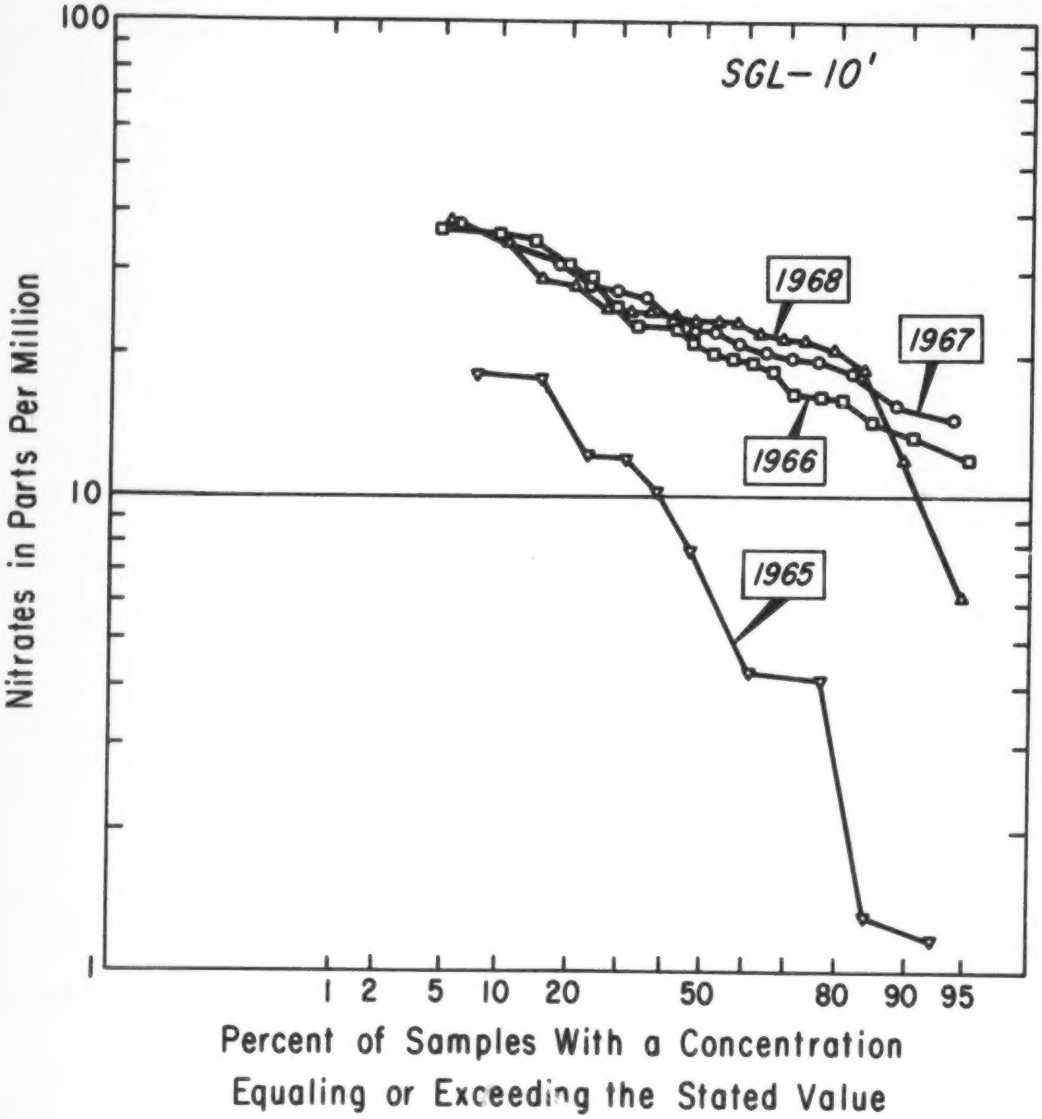

Figure 100. Percent of Deep Trench Lysimeter (SGL) Samples at the Ten-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values.

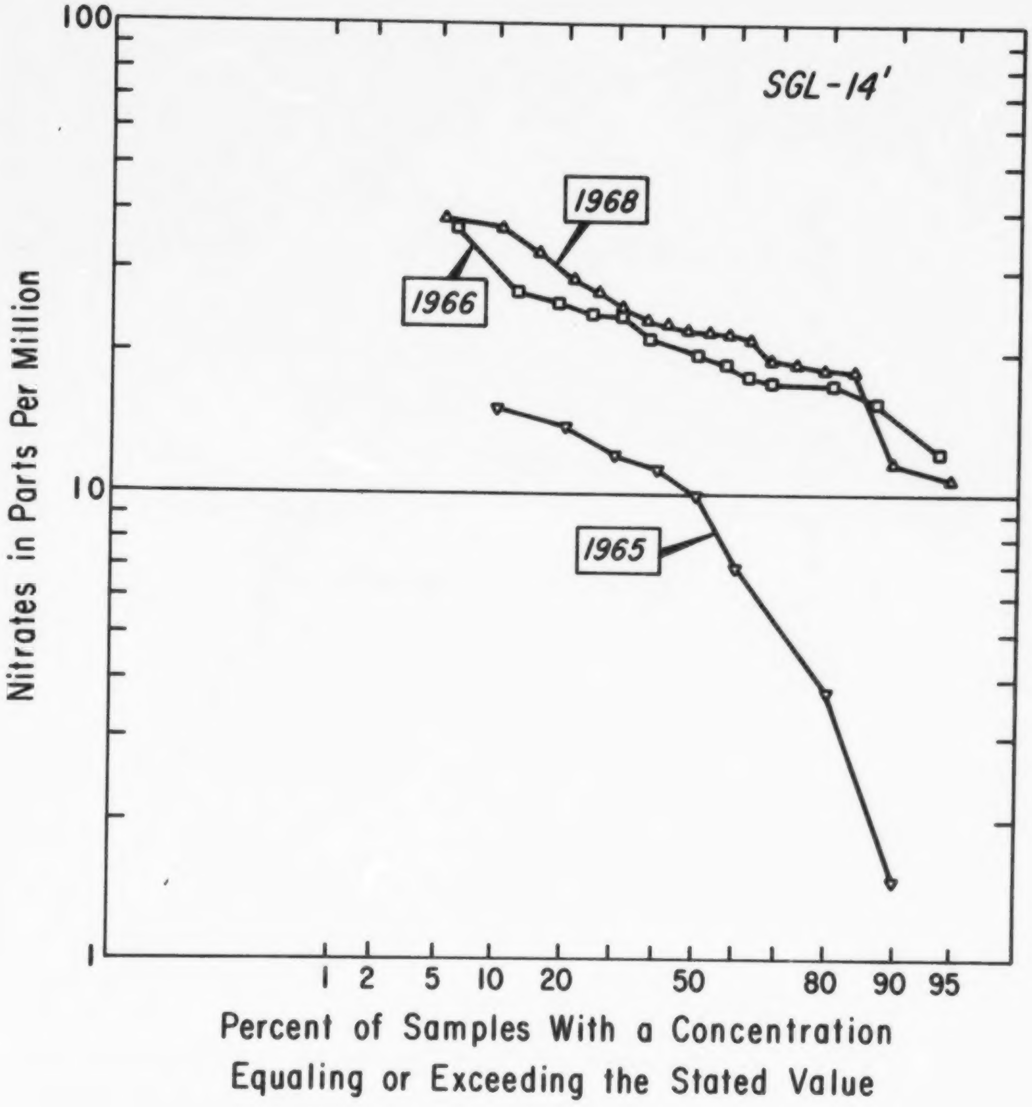

Figure 101. Percent of Deep Trench Lysimeter (SGL) Samples at the 14-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values.

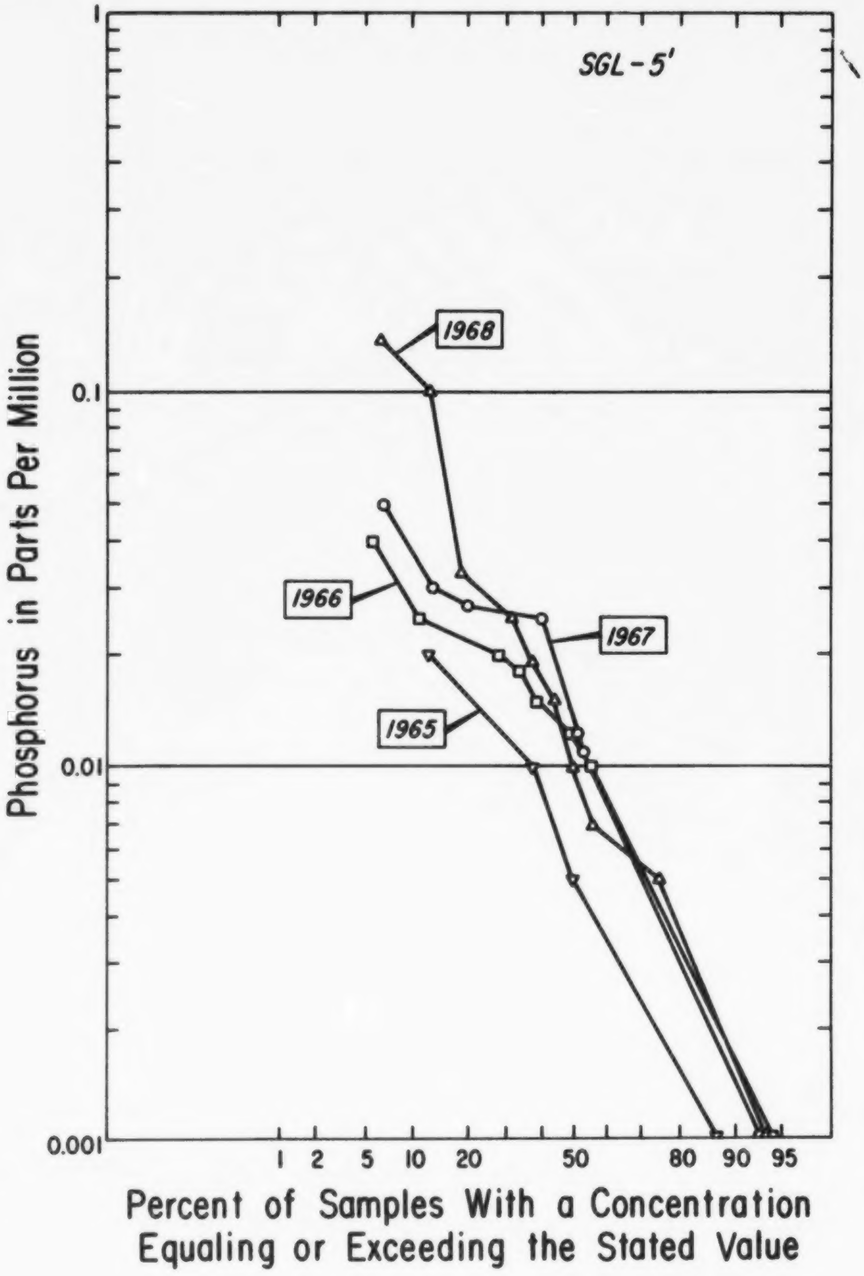

Figure 102. Percent of Deep Trench Lysimeter (SGL) Samples at the Five-foot Depth With P Concentrations Equalling or Exceeding Stated Values.

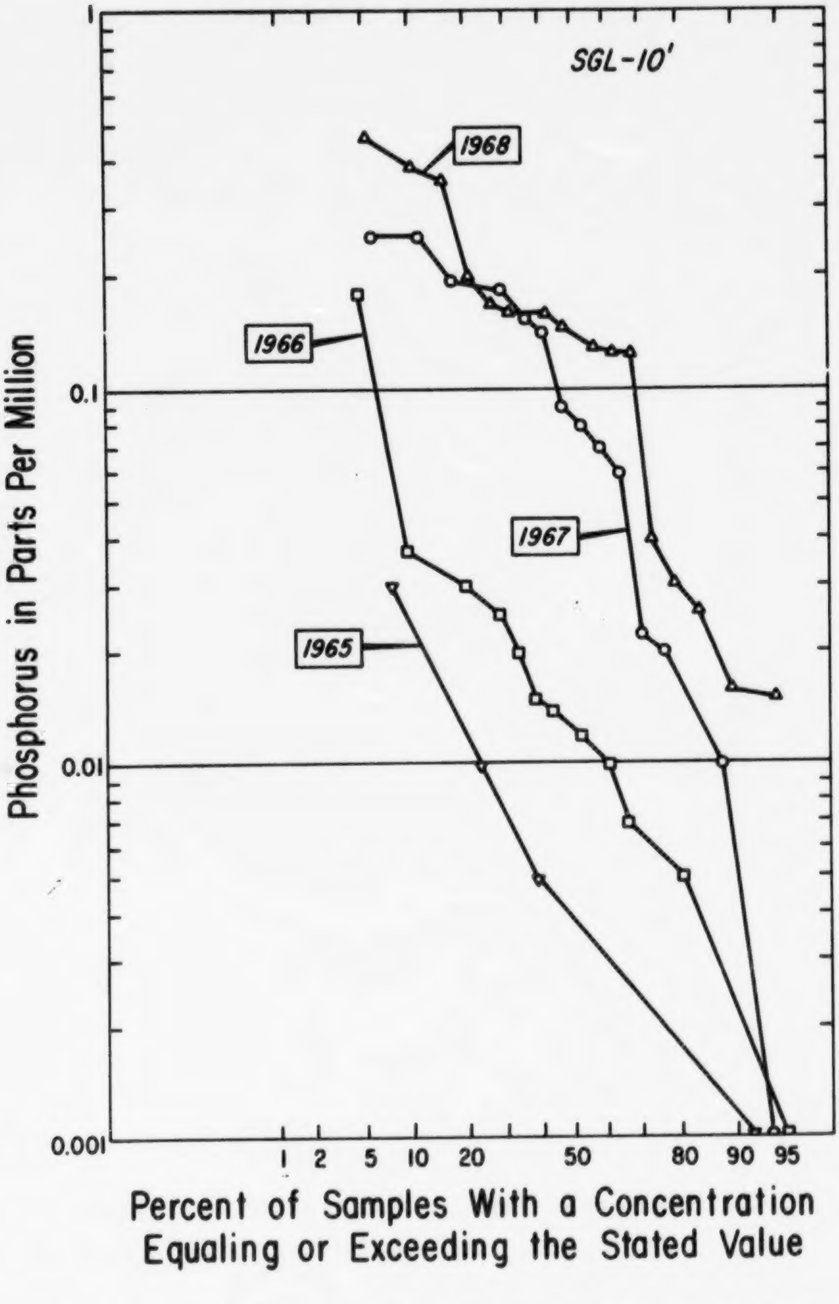

Figure 103. Percent of Deep Trench Lysimeter (SGL) Samples at the Ten-foot Depth With P Concentrations Equalling or Exceeding Stated Values.

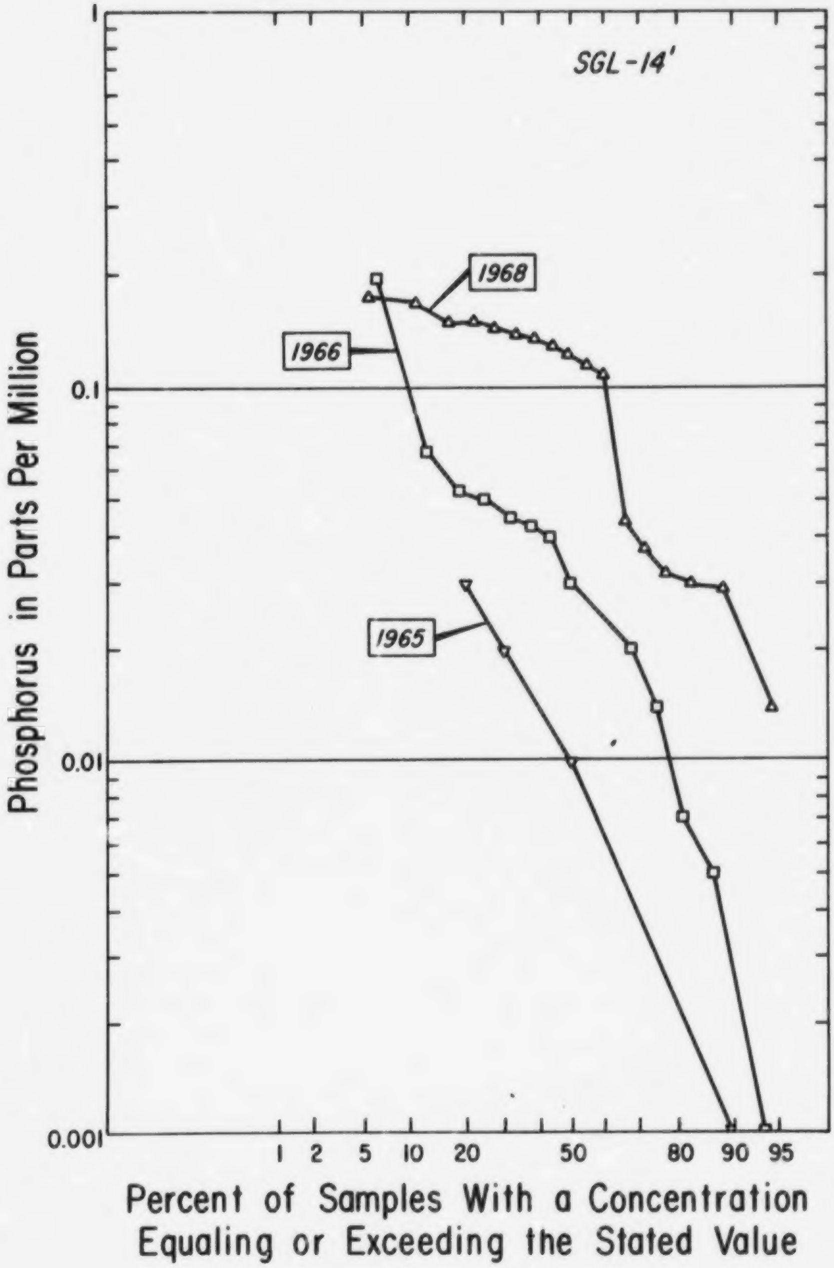

Figure 104. Percent of Deep Trench Lysimeter (SGL) Samples at the 14-foot Depth With P Concentrations Equalling or Exceeding Stated Values.

Table 154. Phosphorus Concentrations Equalled or Exceeded by 20%, 50%, and 80% of the Values for 5, 10, and 14 foot Depths in the Gameland's Trench Lysimeter (SGL).

	Values Equalled or Exceeded by Various Proportions of Values											
	1965			1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft	mg P per liter											
5	.020	.005	.002	.022	.012	.003	.027	.013	.003	.032	.010	.003
10	.012	.004	.002	.030	.013	.005	.190	.084	.017	.220	.140	.030
14	.030	.010	.002	.052	.030	.008	-	-	-	.150	.120	.030

ABS data (Table 155 and Figures 105, 106 and 107) clearly show the influence of overloading the first year. The mean concentration in the applied effluent was 1.61 ppm in 1965, 0.40 ppm in 1966, 0.36 ppm in 1967, and 0.56 ppm in 1968. The values equalled or exceeded by 50% of the values in 1965 are only slightly below that in the applied effluent at the 5-foot depth and attenuated with depth. In 1966 with a lower concentration in the applied effluent the cut back in application amounts from 6 to 4-inch per week was still excessive and no decrease in concentration occurred at 5 feet. The 1967 and 1968 ABS data however do show substantial decreases indicating that the renovation media had been flushed of earlier ABS build up. The 1967-1968 data are more in line with what would be expected if some degree of renovation was being achieved.

Suction Lysimeter Quality. Data are presented only for two suction lysimeter sites. One, SLG-1, was located in the New Gameland Hardwood Area which has been receiving two inches of effluent weekly, year-round since November of 1965 and the other, SLK-1, was located in a cropland area in the Gamelands which has been farmed in a rotation of red clover hay (1966, 1967) and corn (1968) and received two inches of effluent weekly, year-round from July, 1965 until Oct, 1969. Data are

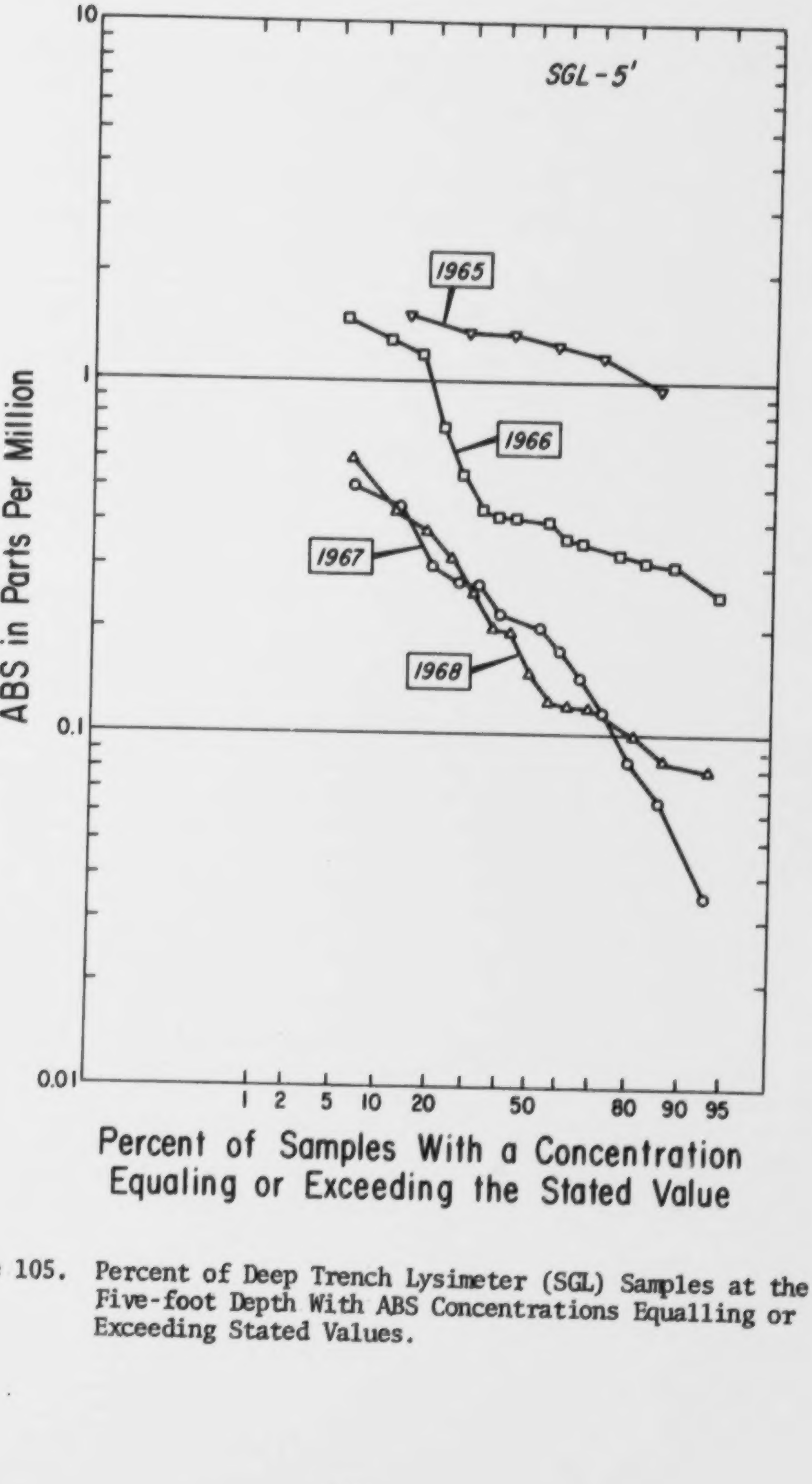

Figure 105. Percent of Deep Trench Lysimeter (SGL) Samples at the Five-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values.

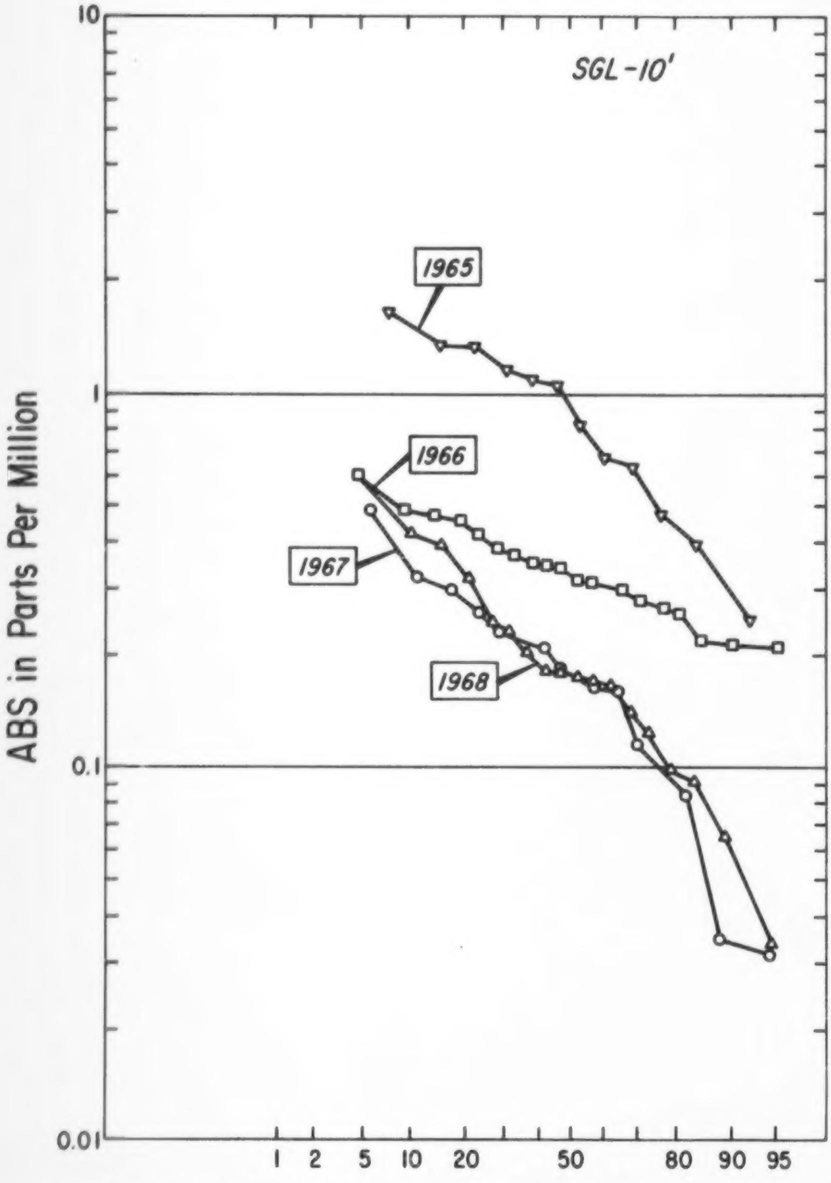

Figure 106. Percent of Deep Trench Lysimeter (SGL) Samples at the Ten-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values.

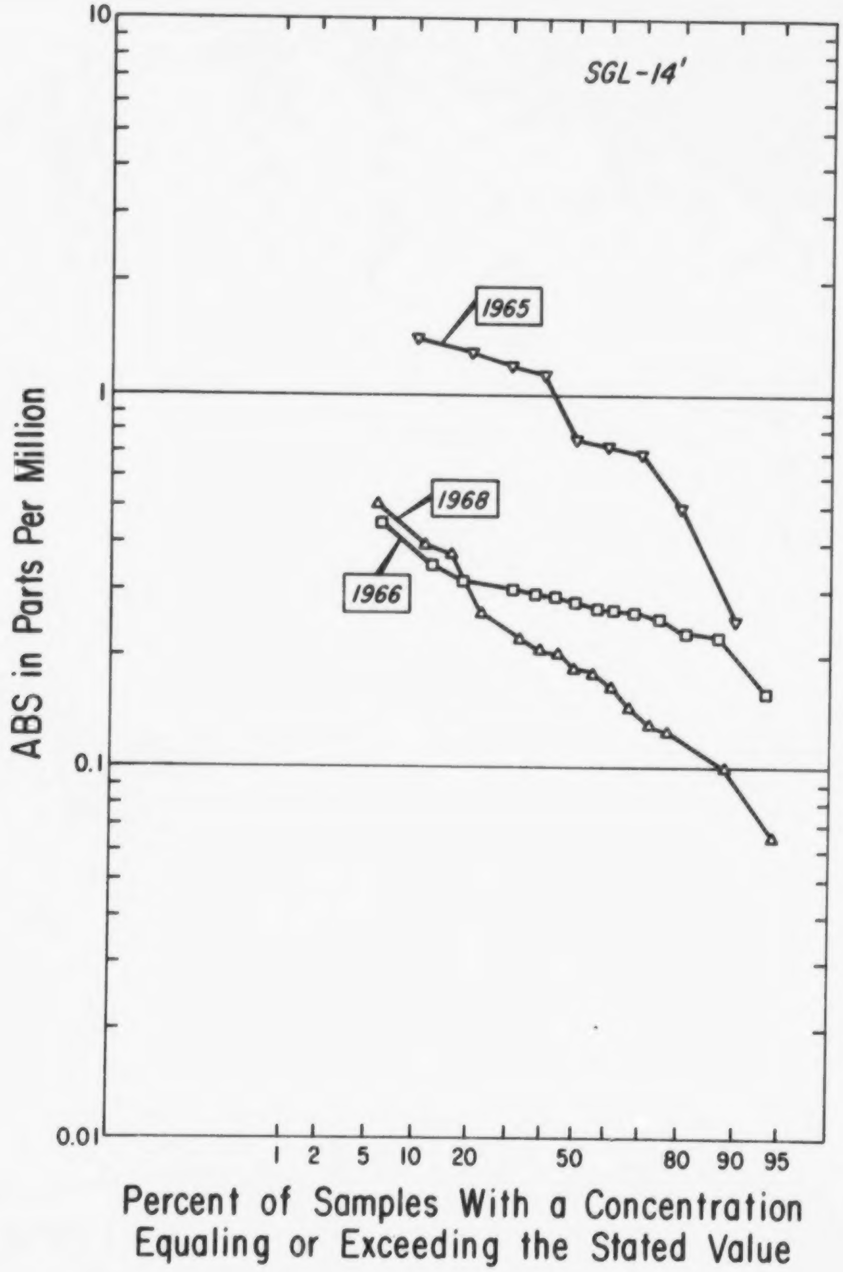

Figure 107. Percent of Deep Trench Lysimeter (SGL) Samples at the 14-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values.

Table 155. ABS Concentrations Equalled or Exceeded by 20%, 50% and 80% of the Values for 5, 10, and 14 foot Depths in the Gameland's Trench Lysimeter (SGL).

	Values Equalled or Exceeded by Various Proportions of Values											
	1965			1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft	mg ABS per liter											
5	1.40	1.30	1.05	0.80	0.40	0.32	0.30	0.21	0.08	0.36	0.15	0.10
10	1.35	0.95	0.45	0.45	0.33	0.26	0.28	0.18	0.09	0.28	0.18	0.10
14	1.30	0.78	0.50	0.31	0.28	0.23	-	-	-	0.30	0.18	0.12

presented for phosphorus, nitrate-nitrogen, chloride and ABS at the 6-, 10.4-, 17.5-, and 20.3-foot depths for SLG-1 and for nitrate-nitrogen at the 7-, and 18-foot depths for SLK-1.

The phosphorus data in Table 156 and Figures 108-109 indicate that the median value at the various depths has remained relatively unchanged or decreased with time and has remained within the background range. In 1968 the median values were 0.013, 0.003, 0.016 and 0.010 mg P/1, respectively, at the 6-, 10.4-, 17.5-, and 20.3-foot depths.

Table 156. Phosphorus Concentrations Equalled or Exceeded by 20%, 50% and 80%, of the Values for 6-, 10.4-, 17.5- and 20.3-foot Lysimeters (SLG-1).

	Values Equalled or Exceeded by Various Proportions of Values								
	1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft	mg P per liter								
6	.055	.022	.006	.068	.017	.002	.032	.013	.002
10.4	.095	.030	.010	.044	.015	.002	.014	.003	.002
17.5	-	-	-	.062	.025	.004	.022	.010	.003
20.3	.082	.025	.007	.065	.027	.002	.035	.010	.002

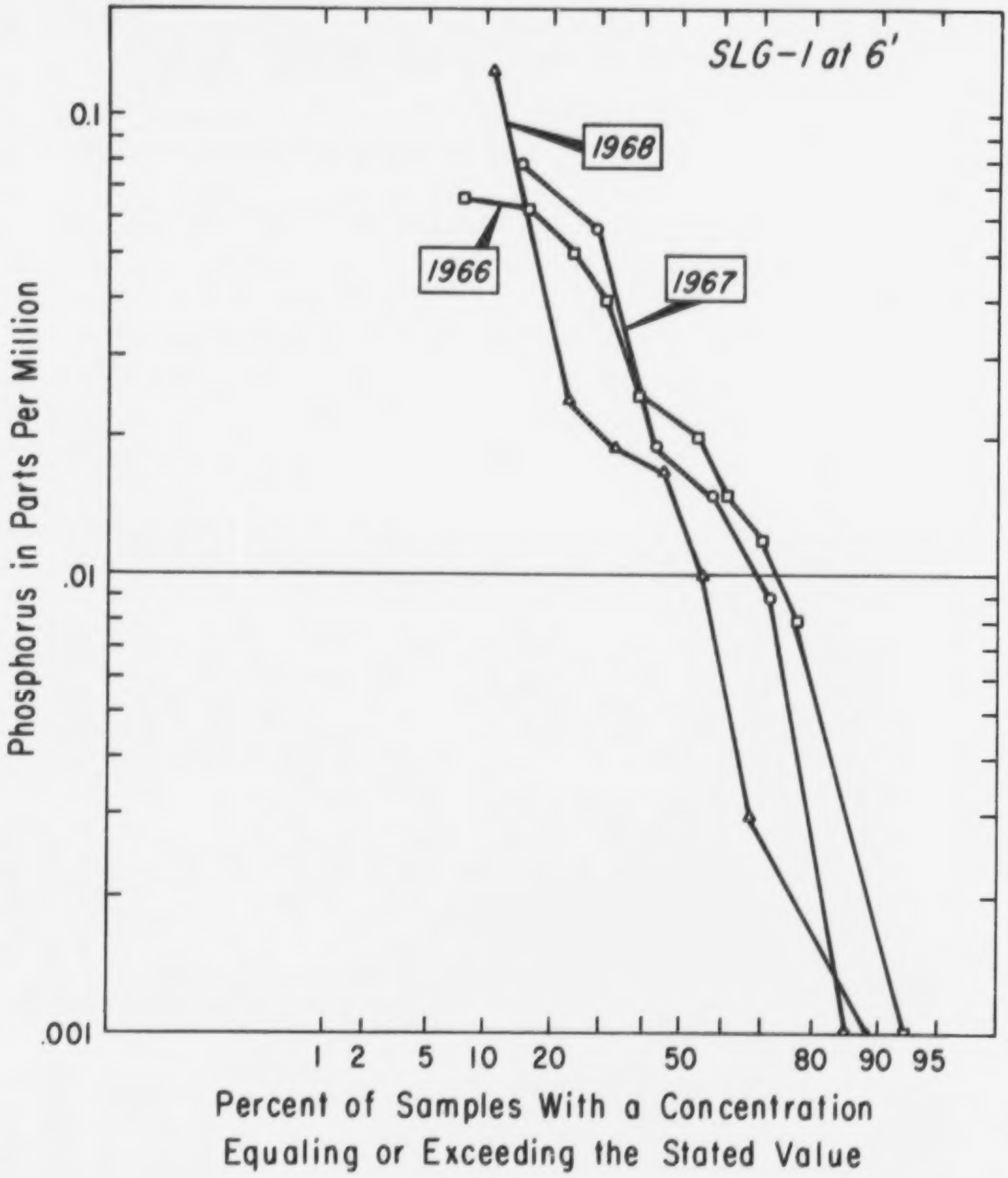

Figure 108. Percent of Deep Suction Lysimeter (SLG-1) Samples at the Six-foot Depth With P Concentrations Equalling or Exceeding Stated Values.

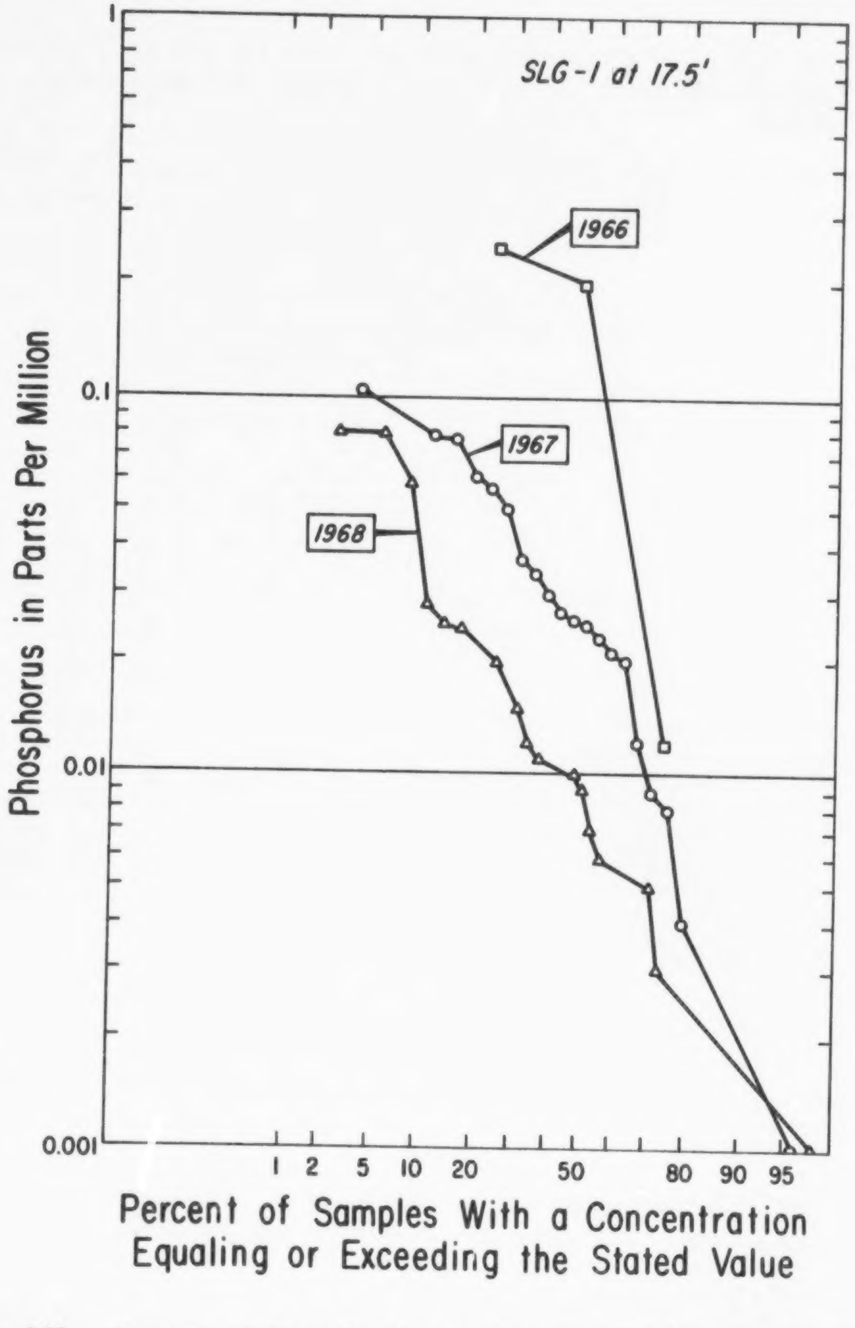

Figure 109. Percent of Deep Suction Lysimeter (SLG-1) Samples at the 17.5-foot Depth With P Concentrations Equalling or Exceeding Stated Values.

ABS values in Table 157 and Figures 110-111 are also well within background limits and have no importance for water quality considerations.

Table 157. ABS Concentrations Equalled or Exceeded by 20%, 50% and 80% of the Values for 6-, 10.4-, 17.5- and 20.3-foot Lysimeters (SLG-1).

	Values Equalled or Exceeded by Various Proportions of Values								
	1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft				mg ABS per liter					
6	0.18	0.08	0.03	0.11	0.03	0.01	0.23	0.07	0.03
10.4	0.09	0.08	0.01	0.14	0.05	0.03	0.11	0.07	0.04
17.5	-	-	-	0.07	0.03	0.01	0.13	0.06	0.03
20.3	0.08	0.05	-	0.08	0.05	0.08	0.08	0.03	0.01

The values for chlorides and nitrate-nitrogen in Tables 158 and 159 and Figures 112, 113, 114, 115 indicate that chlorides had already broken through at all depths in 1966 and that although nitrates had increased substantially over background values by 1966 they increased even more substantially in 1967 and 1968. The lag of nitrate behind chloride is probably due to biological retention and recycling of nitrogen through the forest stand.

The median values for chloride at the 20.3-foot depth were 35, 22, and 20 mg $Cl^-/1$, respectively, in 1966, 1967 and 1968. For nitrate-nitrogen the median values in 1966, 1967 and 1968 were, respectively, 4.0, 14 and 16 at the 6-foot depth, and 3.7, 11 and 20 at the 20.3-foot depth.

The nitrate and chloride values in the suction lysimeters at 6 and 10.3 feet are similar to those found in the trench lysimeters at similar depths. At both sites overloads and undesirable breakthrough of nitrates occurred after approximately 100 inches of effluent had been applied either on a part-year basis at the trench lysimeter site (SGL) or on a year-round basis at the suction lysimeter site (SLG-1).

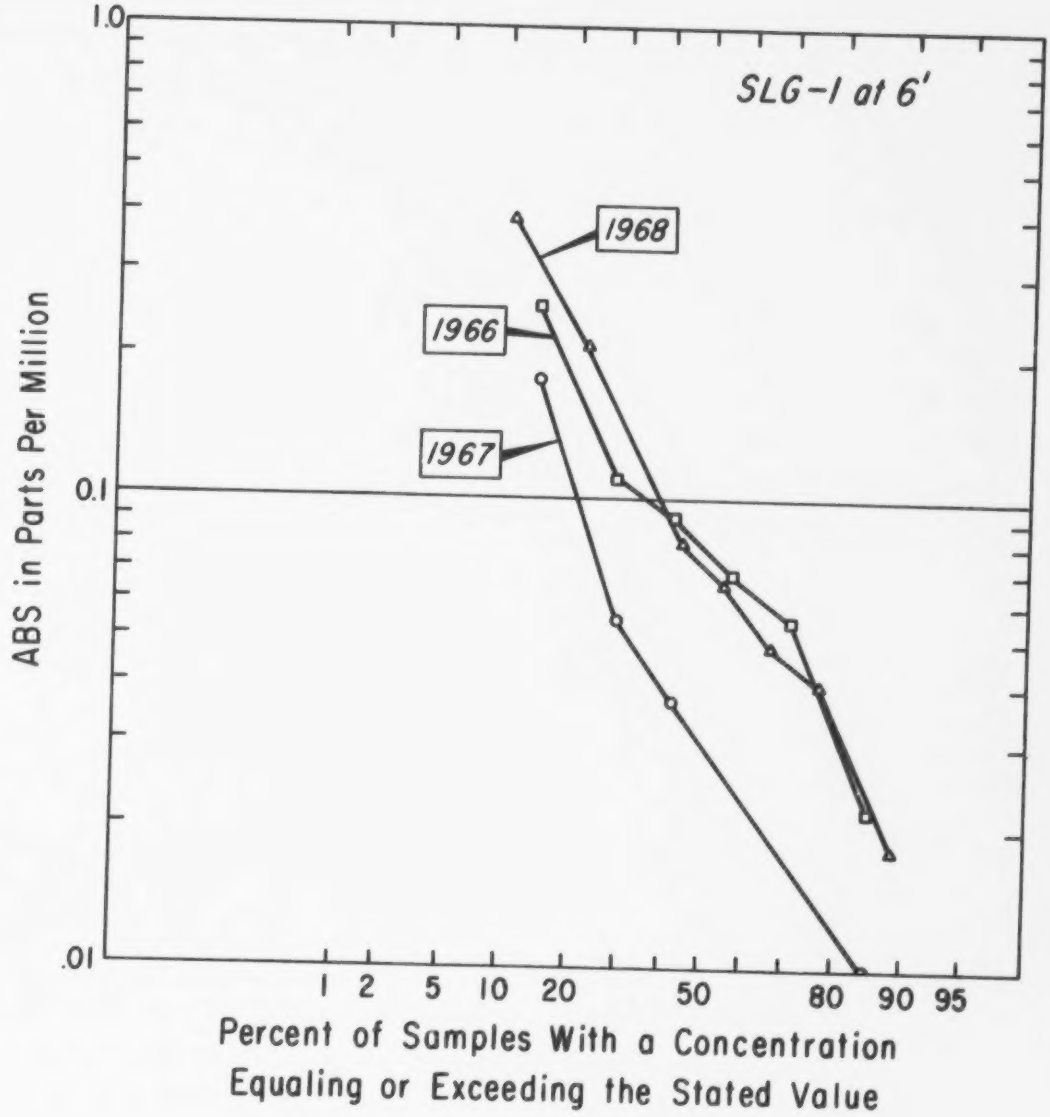

Figure 110. Percent of Deep Suction Lysimeter (SLG-1) Samples at the Six-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values.

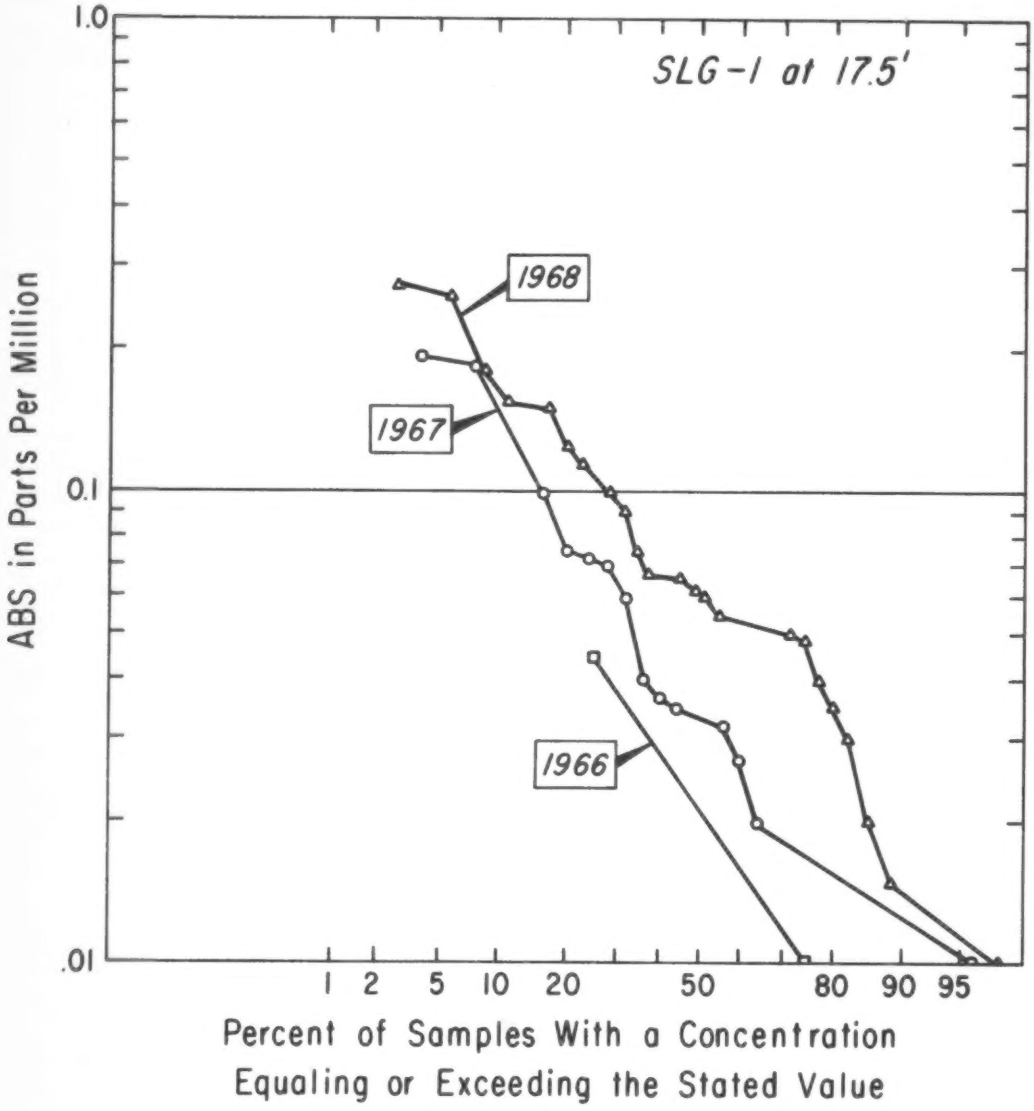

Figure 111. Percent of Deep Suction Lysimeter (SLG-1) Samples at the 17.5-foot Depth With ABS Concentrations Equalling or Exceeding Stated Values.

Table 158. Chloride Concentrations Equalled or Exceeded by 20%, 50%, and 80% of the Values for 6-, 10.4-, 17.5-, and 20.3-foot Lysimeters (SLG-1).

	Values Equalled or Exceeded by Various Proportions of Values								
	1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft	mg Cl^- per liter								
6	48	45	43	43	41	38	47	43	41
10.4	52	32	23	50	47	46	48	46	45
17.5	--	--	--	55	49	45	49	46	44
20.3	42	25	22	37	32	21	25	20	17

Table 159. Nitrate-Nitrogen Concentrations Equalled or Exceeded by 20%, 50%, and 80% of the Values for 6-, 10.4-, 17.5-, and 20.3-foot Lysimeters (SLG-1).

	Values Equalled or Exceeded by Various Proportions of Values								
	1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft	mg NO_3-N per liter								
6	4.5	4.0	0.3	15	14	10	20	16	15
10.4	5.0	4.6	0.3	25	21	12	27	24	20
17.5	--	--	--	22	15	9.8	30	21	18
20.3	5.5	3.7	1.8	15.5	11	6.8	25	20	17

Nitrates in the hay field site (SLK-1) (Table 160) were substantially less than in the hardwood forest site (SLG-1) at similar depths. In 1966 the SLK-1 median value was 1.1 mg NO_3-N/1 at 7 feet whereas the 1966, SLG-1 median value was 4.0 mg NO_3-N/1 at 6 feet. In 1968 the SLK-1 median nitrate value was 8.6 at 18 feet and the SLG-1 median nitrate value was 21 mg NO_3-N/1 at 17.5 feet. The almost two-thirds lower NO_3-N in the cropland site was probably due to the removal of nitrogen in the harvested crops and possibly some denitrification. The SLK-1 site had more clay in the subsoil which caused intermittent

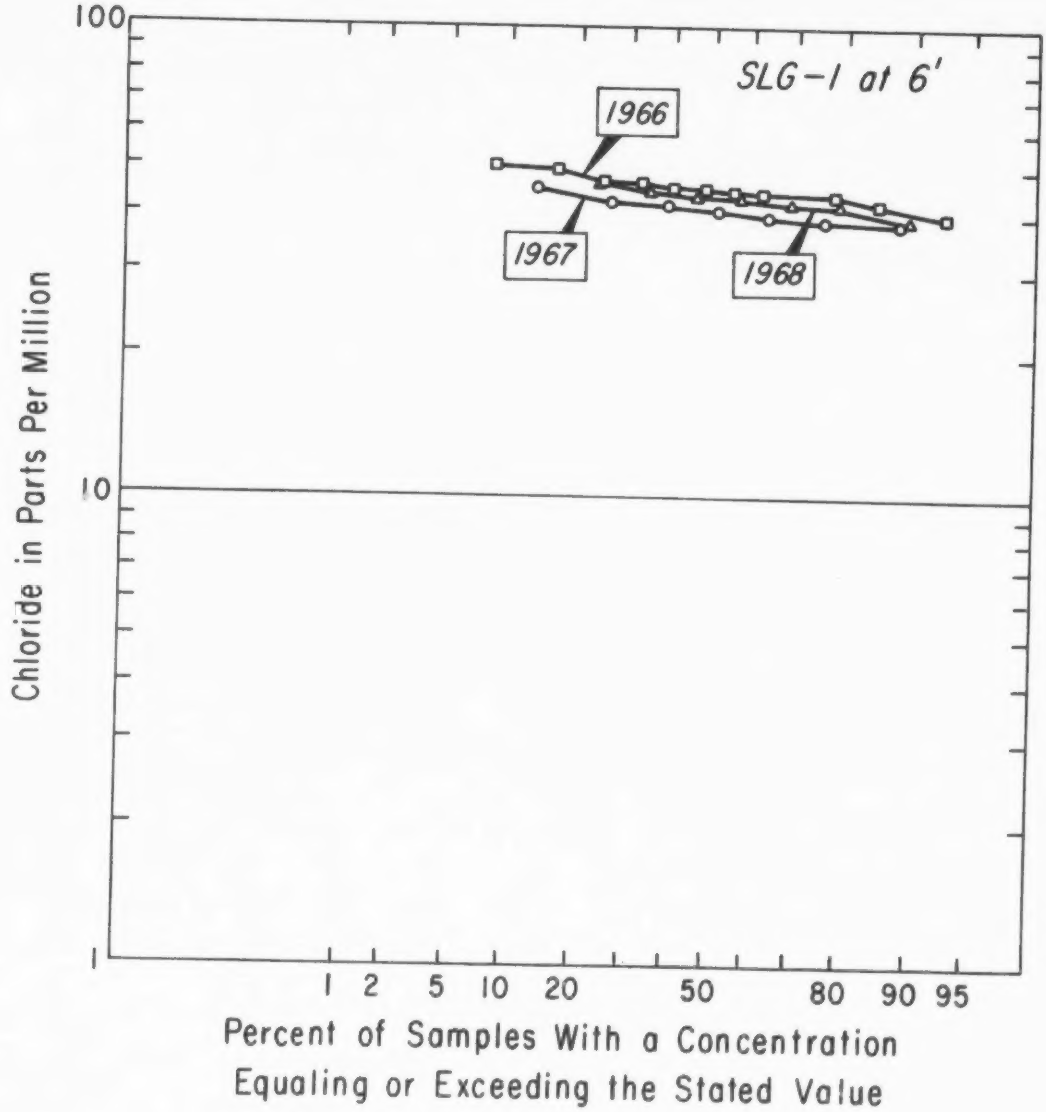

Figure 112. Percent of Deep Suction Lysimeter (SLG-1) Samples at the Six-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values.

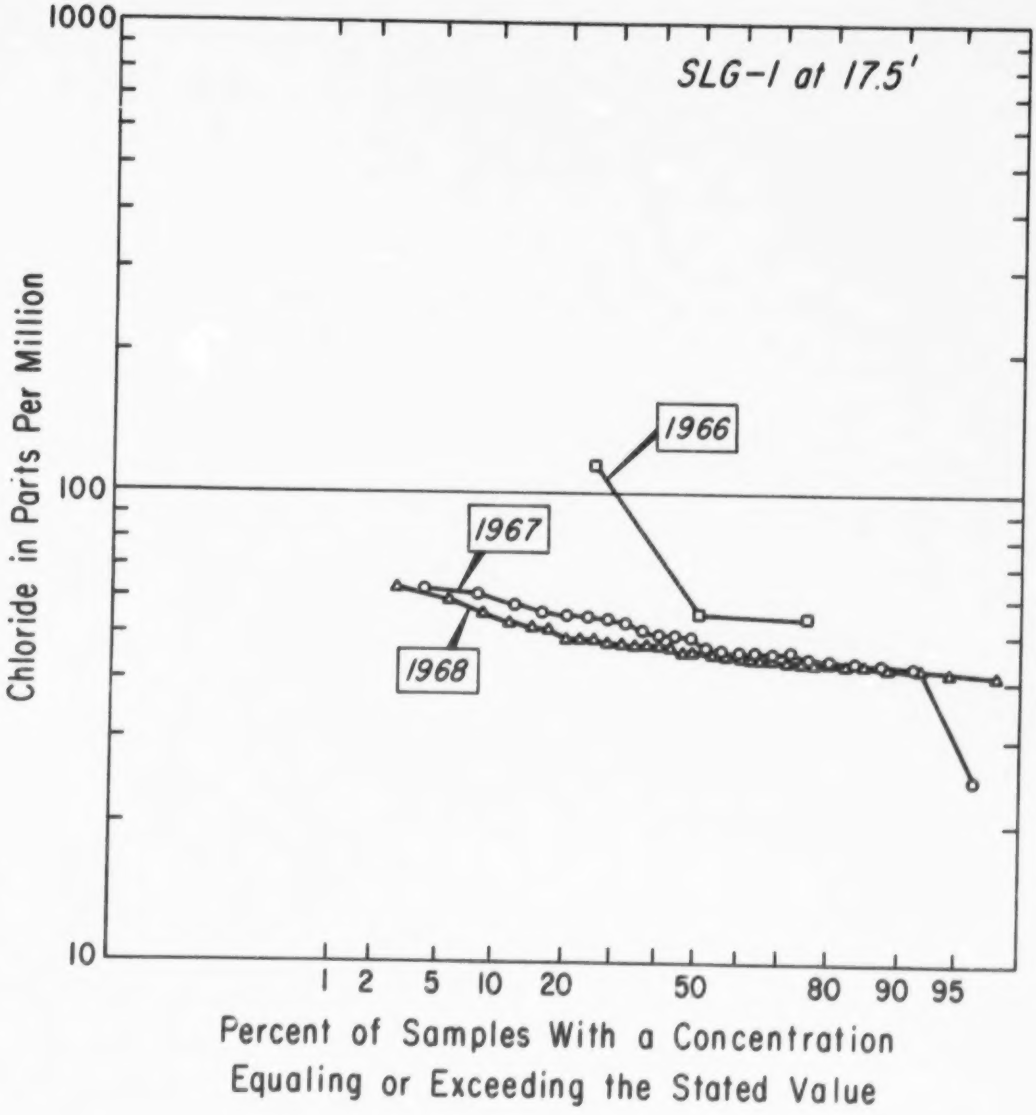

Figure 113. Percent of Deep Suction Lysimeter (SLG-1) Samples at the 17.5-foot Depth With Chloride Concentrations Equalling or Exceeding Stated Values.

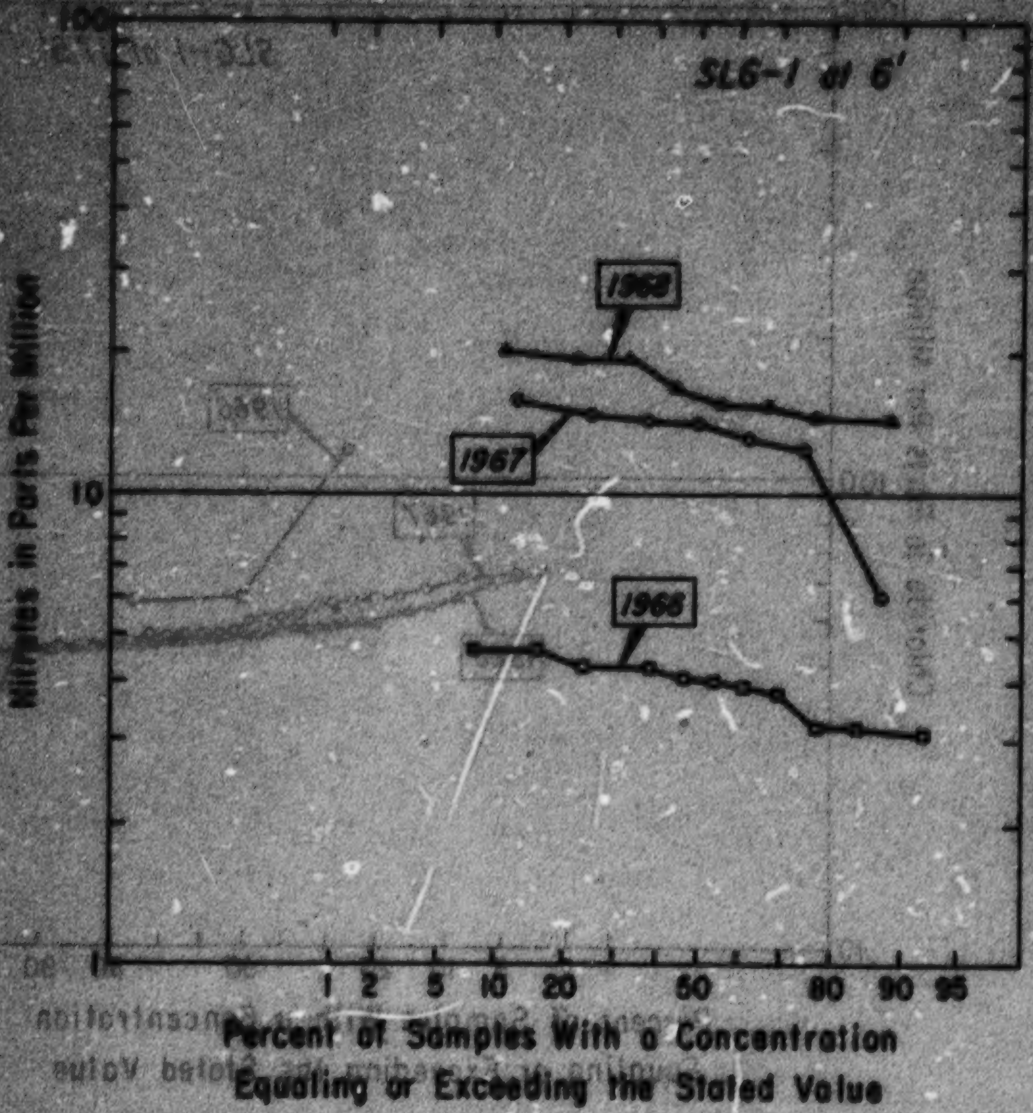

Figure 114. Percent of Deep Suction Lysimeter (SLG-1) Samples at the Six-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values.

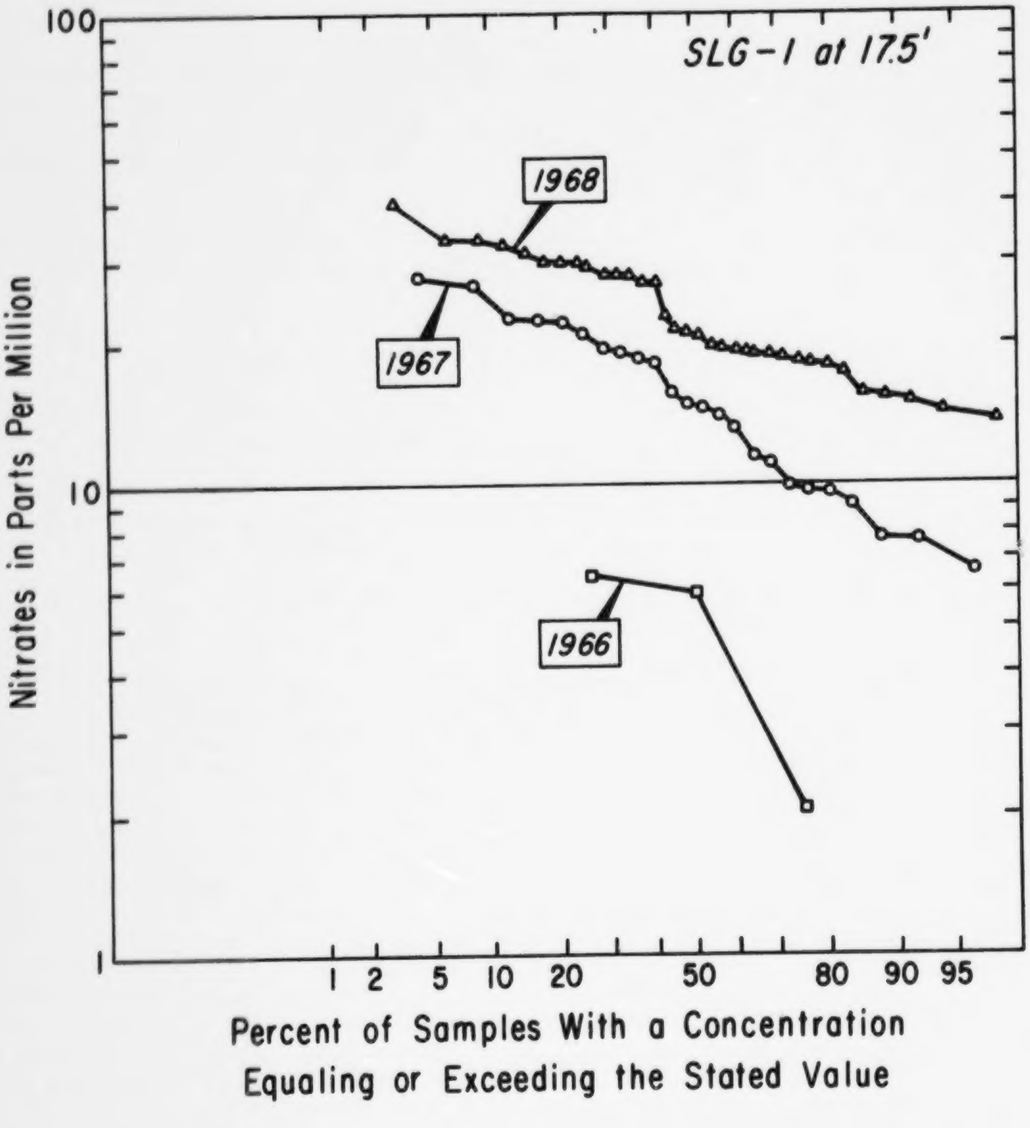

Figure 115. Percent of Deep Suction Lysimeter (SLG-1) Samples at the 17.5-foot Depth With NO_3-N Concentrations Equalling or Exceeding Stated Values.

perching of a shallow water table at a depth of 15 to 20 inches as found by Rebuck (15). Such a hydrologic situation provides conditions favorable to denitrification.

Table 160. Nitrate-Nitrogen Concentrations Equalled or Exceeded by 20%, 50% and 80% of the Values for a Suction Lysimeter, SLK-1, in a Cropland[1] Area at the Gamelands Which Received Two Inches of Effluent Per Week, Year-Round, Since July, 1965

	Values Equalled or Exceeded by Various Proportions of Values								
	1966			1967			1968		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Depth in Ft	mg NO_3-N per liter								
7	4.5	1.1	0.3	15	11	5.5	-	-	-
18	-	-	-	8	5.6	3.6	79	8.6	6.1

[1] Red clover hay in 1966 and 1967, corn in 1968.

In general the suction and pan lysimeter data agree fairly well that nitrate-nitrogen concentrations in the forested sandy soils of the Gamelands Area could be a constraining parameter since concentrations in the soil water exceed the U.S. Public Health Service recommended limit within two years if two inches of effluent is applied at weekly intervals year-round or within one year if four or six inches were applied at weekly intervals for five to six months out of a year. On the other hand the deep well data indicate that concentrations in the well samples remained below U.S.P.H.S. recommended limits. Either the deep wells are not sampling the recharging wastewater, or the latter is being diluted during pumping, or the recharging wastewater is being diluted by recharge flowing from surrounding unirrigated areas into the irrigated area. In any event it would appear more definitive to use the shallow on-site suction lysimeters as indicators of the treatment level attained for weakly absorbed anions and cations. For strongly adsorbed anions like phosphorus and cations such as the heavy metals additional attenuation of concentration can be expected over the entire path length of flow.

GROUND WATER RECHARGE AND REUSE

General Considerations

Sites can be selected with wastewater renovation as the sole purpose or with the added possibility of reuse. Parizek and Myers indicated that site selection criteria for a renovation system favoring distant reuse may be different from those favoring local reuse as groundwater. Shallow penetration of renovated effluent and rapid return to the surface may be acceptable. This can be achieved by irrigating side hill slopes and local uplands that favor the surface return of waters after a sufficient degree of treatment has been achieved. Irrigation on local uplands surrounded by nearby valleys and on stratified deposits favoring the development and lateral movement of perched groundwater are common settings where this can be achieved. Loess overlying glacial till, shale or siltstone bedrock, lake clay, lake silts and sands, fluvitile silts and sands, dune sand, residual and other transported soils that overlie deposits with low permeability characteristics are cases in point. The percentage of land area that would favor renovation but unimportant groundwater recharge is greater for many states than is land that would favor significant increases in groundwater recharge for local reuse.

Groundwater recharge for local reuse may be an important objective at some project sites. Examples have been cited above where infiltration, renovation, and quick return to land surface can be achieved. In these cases, reclaimed effluent may be available for reuse off-site as surface water, it may be recaptured by wells located downstream by induced streambed infiltration, it may be used as surface water for recreational purposes or wildlife propagation or as irrigation water.

Water supply wells may be located beneath or adjacent to irrigation sites to derive benefits of reclaimed water. Wells may be planned to improve drainage as well as to supply water. In both instances, the number and spacing of wells required to provide the necessary amount of water will depend upon aquifer characteristics -- storage, transmission properties, hydrologic boundary conditions, recharge rates -- and degree of treatment anticipated, amount of land to be irrigated, application rates and evapotranspiration requirements.

The number and spacing of onsite wells necessary to insure drainage may depend upon the depth and extent of pumping cones of depression developed for each well, which is related to the number and spacing of wells and aquifer hydrologic characteristics.

Pumping cones of depression within the free-water surface or water table are ideal for dewatering some unconfined soil and rock aquifers and for deriving direct benefit from artificial recharge. Four plans of action are possible: (1) a wastewater renovation facility can be located adjacent to an existing well field where site conditions are suitable for irrigation, and effluent used is free of toxic or harmful nondegradable substances that are not likely to be removed in the renovation media, (2) a well field can be placed in close proximity of the site after it has been established that adequate renovation is being achieved, (3) reclaimed water discharged to surface can be recollected in wells relying upon induced streambed infiltration, or (4) drainage wells can be placed within the irrigation area with no beneficial use planned for the water except to insure adequate drainage.

For all four cases, unconfined aquifers, or at least, semi-unconfined aquifers should underlie the irrigation site. These may be of diverse origin and be composed of fractured bedrock (sandstones, siltstones, carbonate rocks, gneisses and schists) sedimentary rocks containing favorable intergranular or primary permeability (sandstone, siltstone, carbonate rocks) or permeable unconsolidated sediments such as sand and gravel.

Confined aquifers where confining beds are thick or relatively low in permeability, may derive very little more recharge than was being achieved under natural conditions. Once the maximum hydraulic gradient has been developed between the source bed and confined aquifer in response to recharge and pumpage, vertical leakage rates are fixed. Where recharge rates to source beds are in excess of the vertical leakage rate to the confined aquifer, water is rejected from the shallow system and no additional recharge benefits are achieved (9).

Vertical flow rates through confining beds to underlying aquifers can be computed using a form of Darcy law.

$$Q = \frac{P'}{m'} \quad h\ A \qquad (1)$$

where: Q = leakage rate through the confining bed in gallons per day (gpd).

P' = vertical hydraulic conductivity of confining bed, in gallons per day per square foot (gpd/ft^2).

m' = saturated thickness of confining bed in feet.

h = difference in the mean hydraulic head in the aquifer and in the source bed overlying the confining layer, in feet.

A = area of confining bed through which leakage is occurring in square feet.

Selected vertical hydraulic conductivities for soil and rock units are given by Parizek (9).

Groundwater Recharge

The amount of renovated effluent recharged to the groundwater reservoir was estimated from data available on the total amount of effluent and rainfall applied on the plots during the irrigation period, and potential evapotranspiration estimated by the Thornthwaite and Mather (99,100) method. Recharge ranged from 1.1 to 1.8 million gallons per acre with an average of 1.6 million gallons (Table 161). Averaged over the seven year interval recharge amounted to approximately 95 percent of the effluent applied at the 2 inches per week rate.

Recharge rates were higher when water was applied during years with normal or above normal rainfall or throughout the year. Evapotranspiration losses are greatly diminished during the late fall, winter, and spring and more of the water infiltrating into the soil from natural precipitation and irrigation is potentially available for groundwater recharge. Maximum recharge amounts from applied effluent approximate 2.8 million gallons per acre where 2 inches per week are applied on a year around basis.

Runoff which did occur at the irrigation sites following snow and ice pack melt or heavy or prolonged rains was ponded in one or more closed surface depressions where it was captured by infiltration or it infiltrated in adjacent unirrigated buffer areas which were usually in forest cover. Closed depressions were numerous on all of the upland areas selected for irrigation or they were available downslope from test plots, hence detention storage was provided naturally. This would not necessarily be true at other irrigation sites where detention storage would have to be engineered to prevent or eliminate runoff.

It was found that adjacent border areas with forest stands were ideal to help contain runoff and promote infiltration all seasons of the year. Rarely did overland flow extend more than 100 feet beyond irrigation plots during the spring thaw.

Effect of Recharge on Water Levels

Recharge amounts are still somewhat limited at the experimental sites due to their relatively small size. Only 500,000 gallons of effluent are being applied per day divided between two locations 1½ miles apart. Moreover, recharge at the Agronomy-Forestry site has not been sufficient to maintain the elevation of a local groundwater mound (Figs. 4 & 5) which existed before irrigation was started. Water level declines noted in Figure 116 show that recharge was not sufficient to reverse the downward water level trend in the immediate vicinity of the Agronomy-Forestry site. The rate and amount of decline was slowed but still dominated by a downward trend related to the drought (1961-1967), to continued groundwater discharge to springs and to prolonged pumping from the nearby University well field.

Table 161. Estimates of Recharge to the Groundwater Reservoir on Each Acre Receiving Two Inches of Effluent Per Week.

Irrigation Period	No. of Irrigations	Effluent Applied	Rainfall	PET1/	Groundwater Recharge	% Recharge2/
		gallons/acre	gallons/acre		gallons/acre	
June 18-Dec 5, 1963	23	1,249,000	447,500	583,500	1,113,000	89
Apr 8-Nov 18, 1964	33	1,792,000	460,800	650,800	1,602,000	89
Apr 20-Nov 16, 1965	31	1,684,000	444,800	635,800	1,493,000	89
Apr 5-Nov 15, 1966	32	1,738,000	553,900	637,900	1,654,000	95
Apr 18-Oct 31, 1967	28	1,521,000	745,600	407,600	1,859,000	100
Apr 9-Nov 12, 1968	32	1,738,000	700,000	591,000	1,847,000	100
Apr 15-Oct 29, 1969	21	1,140,000	589,500	396,000	1,333,500	100
Average					1,557,000	95

1/ Potential evapotranspiration calculated by method of Thornthwaite and Mather (99,100)

2/ Expressed on basis of effluent applied

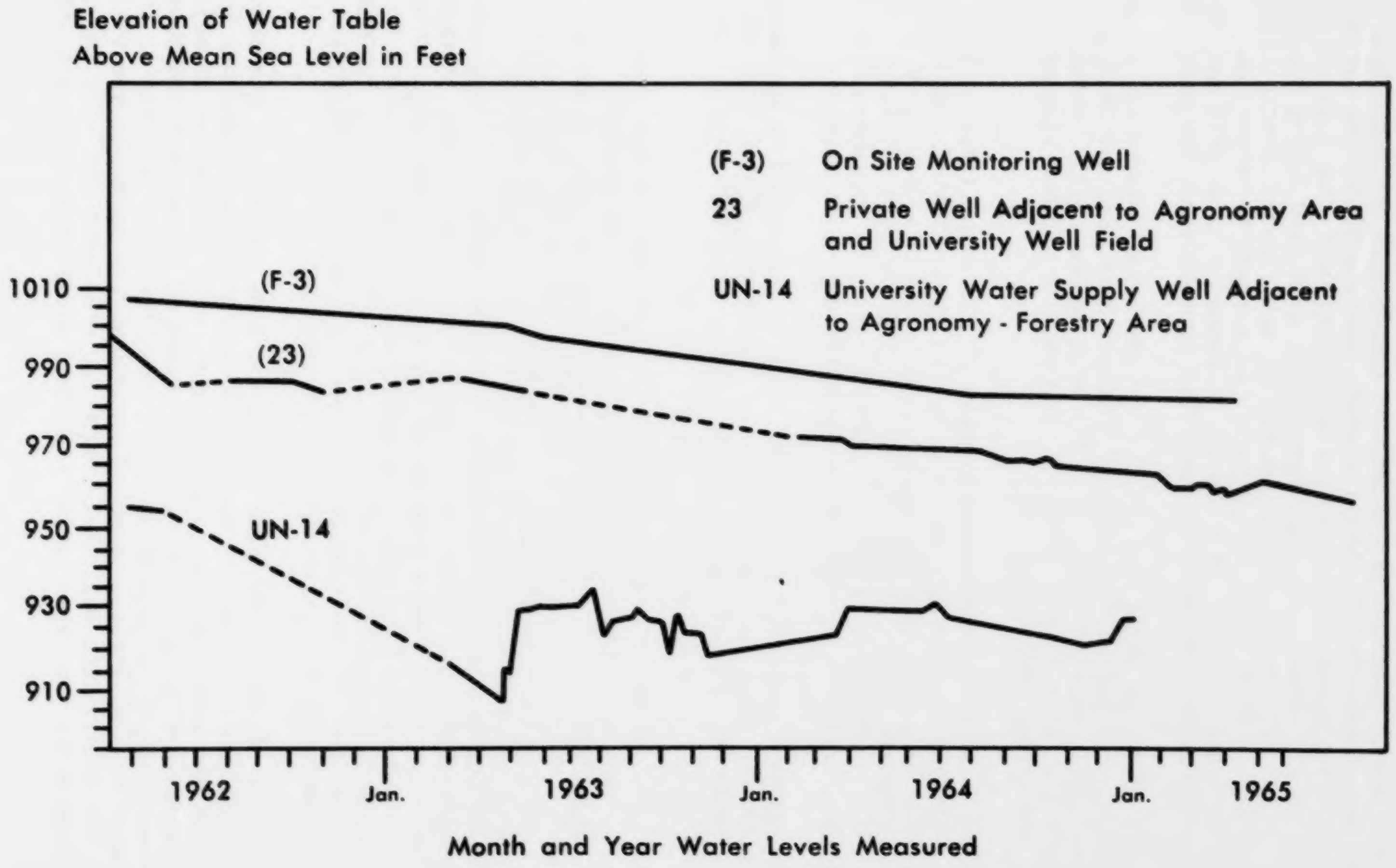

Figure 116. Water Level Declines in Selected Wells.

Water levels recorded in F-3 located immediately downslope from the Agronomy-Forestry site showed a steady decline during the period 1962 to May 1965 until it failed as a monitoring well (Fig 116). A private well (W-23) showed a similar trend until it failed during September of 1965. With return to near normal or above normal precipitation starting in 1967, groundwater levels have begun to recover on a slow but persistent basis. Well 23 was reopened in April 1973 and the water level had recovered by more than 72 feet since September 1965.

Water levels in UN-14, potentially the principal benefactor of reclaimed effluent at the Agronomy-Forestry site, did not decline as drastically as W-23. This well has been pumped nearly continuously since 1963 when it was first put into service and has also responded to the wetter years since 1967.

As an alternate to direct measurement of the water table buildup resulting from recharge, which could not be determined, recharge effects have been computed using recharge amounts determined by the Thornthwaite or Blaney-Criddle methods and the best estimates of aquifer storage and transmission characteristics evaluated from field pumping tests and by regional groundwater depletion studies.

The computed water level responses must be considered as approximate in view of the anisotropic nature of the aquifer system involved and the methods used to compute aquifer storage and transmission characteristics.

The residual mound that should be attributed to recharge from spray irrigation cannot be computed exactly because the permeability and storage properties of the fractured dolomite and sandy dolomite aquifer that underlie the site cannot be determined precisely using existing analytical techniques. Pumping tests were conducted on University water supply wells for this purpose (UN-2, 14, 16, 17, 20, 24, 25 and 26) and best estimates of coefficients of storage and transmissivity are summarized in Table 162. Coefficients of transmissivity ranged from a high of 58,000 in a test (not shown in Table 162) to a low of 3260 gpd/ft depending upon whether a production or observation well was located on a single zone of fracture concentration, at the intersection of two zones of fracture concentration or in adjacent more massive and less jointed rock.

The cone of depression tends to migrate more rapidly along avenues of high permeability causing more drawdown along these zones than for points the same distance from the pumped well but located in adjacent more massive blocks of rock. Small drawdown values obtained from observation wells located in less productive rock but close to the pumped well will yield computed transmissivity values in the vicinity of the observation well that frequently are lower than when the observation wells are later pumped and other observation wells are used to obtain time-drawdown data. This discrepancy is shown in Table 162 for the case of UN-25 which yielded a transmissivity value of 32400 as an observation well during a production test on UN-2, and a 3370 value when UN-25 was pumped. The anisotropic character of the local aquifer is obvious from these data.

Coefficients of storage determined from these same pumping tests ranged from 1.4×10^{-3} to 5.6×10^{-5}. These seemingly low values are typical of carbonate aquifers in central Pennsylvania and are in the artesian range despite the fact that the aquifer is under water table conditions. Coefficient of storage values are expected to be slightly higher than those computed from these 24 to 48 hour pumping tests because when these fractured rocks are subjected to prolonged periods of drainage of a week or more storage values should increase. The delayed drainage would occur from vugs, minor fractures and intergranular openings.

Gravity yield values which are a measure of the storage properties of soil and rock have been determined by an alternate method for all of the carbonate and non-carbonate rocks in Spring Creek basin drained during a given period of groundwater depletion. The irrigated areas are included in this basin which is approximately 175 square miles in area. Groundwater runoff was determined using a mean groundwater stage, groundwater runoff rating curve prepared when all flow leaving the basin was known to be groundwater. Gravity yield was determined using the relationship:

$$Sg = H\ (Yg) \qquad (2)$$

Where Sg is the change in groundwater storage during an inventory period
H is the corresponding change in mean groundwater stage and
Yg is the gravity yield.

The gravity yield of a rock or soil after saturation or partial saturation is taken as the ratio of the volume of water it will yield by gravity to its own volume, during a given period of groundwater recession.

During periods of recession, in which there is no recharge and no surface runoff, the change in groundwater storage is approximately equal to the volume of groundwater runoff, as measured at the stream gaging station.

An average gravity yield of 1.5% was computed for the volume of rock dewatered during the period of water table decline. For prolonged periods of drainage the ultimate gravity yield value is equal to the specific yield. The specific yield is the ratio of the volume of water which soil and rock will ultimately yield by gravity to the volume of soil and rock.

Table 162. Selected Values for Coefficients of Transmissivity and Storage Obtained from Pumping Tests Conducted in the University Well Field (Modified from S. H. Siddiqui, 1969) (101)

With UN-2 as a pumping well			
Observation Wells	Average Coefficient of Transmissivity (gpd/ft)1/		Average Coefficient of Storage x10^5
UN-3	14,800		14.0
UN-26	35,500		5.6
UN-4	21,200		140.0
UN-25	32,400		90.0
UN-16	2,700		30.0
UN-20	37,650		90.0
Mean	24,000	Mean	60.0
With UN-25 as a pumping well and observation well			
Observation Wells	Average Coefficient of Transmissivity (gpd/ft)1/		Average Coefficient of Storage x10^5
UN-25	3,370		70.0
UN-4	4,360		30.0
UN-3	3,260		9.0
Mean	3,663	Mean	36.0

1/ Average values of coefficients of transmissivity and storage are based on semi-log time drawdown and log log time-drawdown methods of analysis.

Parizek (102) and Konikow (103) have shown that both values can vary with the mean depth of the water table and that normally these decrease as the depth to the water table increases in fractured rocks.

The 1.5% average regional gravity yield value is considered as being slightly too low for the aquifer beneath the irrigation plots. The Upper Sandy Dolomite member of the Gatesburg Formation contains 5 to 35 foot thick beds of dolomitic sandstone, sandy dolomite and loosely cemented sandstone interbedded with fine-to coarse-grained dolomite. Drill cores obtained from this formation at the Agronomy Forestry site and Gamelands site were tested for porosity. Intergranular and vug porosity contained in core samples were included in testing for porosity while enlarged openings along bedding planes, joints and along selected bedrock units were excluded by nature of the sampling procedure used.

Smith (104) studied porosity development using cores of the Gatesburg Formation in the genetically related sedimentological system quartz sandstone-dolomite. Both quartz sandstone and nearly pure dolomite end-member samples were studied as were samples containing various proportions of each.

For the dolomite end-member, porosity was found associated with the size of the dolomite grains and sorting of grains of quartz, the principle insoluble residue. Both a decrease in the size of dolomite grains and an increase in sorting of quartz grains results in increased porosity. A comparatively rapid increase in porosity was found beyond 50 to 60 percent quartz content (insoluble residue), which relates to an increase in the quartz-grain supported framework. For rocks with more than 50 to 60 percent insoluble residue, the degree of packing and amount of residue were the two petrographic properties, of the thirteen measured, which were most strongly associated with porosity values. Porosity values of core samples ranged from less than 1% for pure dolomite to nearly 20% for nearly pure sandstone. A greater proportion of the rock beneath the irrigation site is dolomite. An average porosity value of 5 to 8% might be more typical of the Gatesburg Formation rocks. Therefore a gravity yield of 3% or higher in contrast to the 1.5% value computed for the 175 square mile drainage basin should be more typical for the rocks underlying the irrigation site. This would vary to some extent depending upon the position of the water table with respect to individual bedrock units being saturated or dewatered following changes in the water table elevation.

The water table build up in UN-14 and 24 that should have accompanied two years of recharge at the Agronomy Forestry site (the time required to approach steady state condition) was computed using selected average values for the coefficients of storage, gravity yield, and coefficient of transmissivity obtained from the studies outlined above. Groundwater recharge was taken as 65,000,000 gallons/year based on precipitation data, potential evapotranspiration computations and the number of acres irrigated at the Agronomy Forestry site (105). This recharge amount was assumed based on irrigating 19.5 acres at 2-inches per week April-November, 18 acres year around at 2-inches per week, 6 acres at 1-inch per week April-November and the high recharge rate of 1,856,000 gallons/acre/year for the 2-inch per week application amount.

The influence of recharge by reclaimed effluent on local groundwater levels cannot be measured directly on site for the reasons stated; i.e., falling regional water levels due to natural discharge to major springs, related to prolonged drought conditions, and the superposition of these declines on water level declines in the area of influence of the University well field. These regional influences on water levels are far more pronounced and have masked the effect of water level buildups in response to spray irrigation.

Allowing for the uncertainty in computing coefficients of storage and transmissivity for the local aquifer in the vicinity of the University well field and the Agronomy-Forestry irrigation site, the amount of water table buildup resulting from recharging 65 million gallons of water a year may be estimated using Theis (106) nonequilibrium formula and the law of superposition.

Drawdowns or water level buildups in response to either pumping or recharge wells may be computed using equation

$$s = (114.6Q/T)\ W(u) \tag{3}$$

Where: $W(u) = \int_{u}^{\infty} e^{-u}/u\ du = 0.5772 - \ln u + u - (u^2/2.2!) + (u^3/3.3!) - (u^4/4.4!) \ldots$

and $$u = 2693r^2S/Tt \tag{4}$$

s = drawdown or buildup in an observation well, in feet
Q = discharge or recharge in a well, in gallons per minute
T = coefficient of transmissivity, in gallons per day/ft
r = distance from pumped or recharged well to the observation well in feet
S = coefficient of storage, a fraction
t = time since pumping or recharge started, in minutes.

Equation (3) is the nonequilibrium artesian formula introduced by Theis (106). W(u) is the "well function for nonleaky artesian aquifers. Values of W(u) and u that allow for the evaluation of the integral are given by Wenzel (107). Equations (3) and (4) or modifications of them were used to compute coefficients for storage and transmissivity initially given time-drawdowns field data obtained from various pumping tests conducted on wells in the University well field and adjacent areas. Time-drawdown field data curves were matched to the nonleaky artesian type curve and match point coordinates W(u), 1/u, s, and t were substituted in equations (3) and (4) to determine aquifer coefficients.

Given estimated average values of these coefficients obtained by the pumping test method, gravity yield values obtained by the groundwater depletion method, and porosity values obtained by core analysis, equations (3) and (4) were again used to compute the water level buildup, s, that would result at wells UN-14 and UN-24 following two years of recharge. Recharge amounts computed in gallons per acre per year using the Blaney Criddle or Thornthwaite method were distributed evenly among 26 assumed wells spaced throughout the irrigated areas and were expressed in gallons per minute, Q. The distance r, in feet was measured between each assumed recharge well and UN-14 and UN-24. Equations (3) and (4) were solved 26 separate times using a computer solution devised for the purpose and the water level buildup from each assumed recharge well was added to the buildup caused by each of the other 25 recharge wells. The law of superposition allows the buildup of all 26 wells to be added at any observation well location to give the total buildup in feet. This gives the total water level rise that should result in response to recharge of reclaimed effluent and precipitation at the irrigation sites. To determine the actual change in groundwater levels in the region, this buildup must be added to groundwater level declines in response to natural groundwater discharge and recharge, and declines due to groundwater pumpage which requires a regional analysis of the entire groundwater system. This analysis was not conducted for the purposes of this study but it is clear that due to the small acreage irrigated regional effects will dominate. This is revealed by the continued water level declines observed in wells F-3, 23, UN-14, 24 and 17, SC-5 and 18 and other observation wells in the region despite the recharge derived from the irrigation project.

Computed water level rises in response to spray irrigation shown in Table 163 must be considered as approximate because the carbonate aquifer beneath and adjacent to the irrigation site is less than homogeneous and isotropic as assumed by the Theis theory. However, computed buildups are probably the correct order of magnitude.

In case one, coefficients of transmissivity and storage were assumed to be 40,000 gpd/ft and 0.03. Under these conditions, a buildup of approximately 2.02 feet was computed for UN-14 which was 1300 feet from the recharge site and 1.7 feet at UN-24 which was 2200 feet away. If recharge were increased by 50% during wetter years a water table buildup due to irrigation may have approached 3.0 feet at UN-14 and 2.6 feet at UN-24. Any actual significant decrease in either the coefficient of storage or transmissivity values, an entirely plausable condition, would result in a greater buildup in water levels in response to irrigation. For example, the same coefficient of transmissivity (40,000 gpd/ft), 65,000,000 gallons of recharge per year, and an average coefficient of storage of .0006 as determined from pumping tests conducted in the well field would have resulted in 3.4 feet of rise in UN-14 and 3.1 feet in UN-24.

Also, some of the pumping test data suggest that the average coefficient of transmissivity of the dolomite to sandy dolomite aquifer that underlies the Agronomy-Forestry site might be as low as 20,000 gpd/ft. Even lower values were measured for less productive blocks of bedrock that may vary from 5 to 20 acres in area. Flowing fine-to medium-grained sand and silt are common in most voids in the bedrock within the upper 100 to 300 feet of landsurface. Cavity fill deposits would further reduce the storage and transmission properties of these rocks compared to what might be expected for dolomite bedrock in nearby areas.

An average coefficient of transmissivity of 24,000 gallons per day/ft was determined for the Gatesburg aquifer using one pumping well (UN-2) and six nearby observation wells (Table 162). Even lower average values of 3,660 gpd/ft were determined from other tests. It is entirely possible that bulk transmission characteristics of these rocks considering both high avenues of permeability and blocks of poorly productive rock could be as low as 20,000 gpd/ft. This combined with a possible average coefficient of storage value as low as .0006 and a 6.5×10^7 gallons of recharge per year could have caused a potential buildup of 6.3 feet in UN-14 and 5.7 feet in UN-24 (Table 163).

Table 163. Relation Between Aquifer Hydraulic Properties and Water Table Buildup for Two University Water Supply Wells

Aquifer Hydraulic Properties		Water level Buildup-ft[1/]	
Coefficient of Transmissivity gpd/ft	Coefficient of Storage	UN-14	UN-24
40,000	0.03	2.0	1.7
	0.0006	3.4	3.1
20,000	0.03	3.6	2.9
	0.0006	6.3	5.7

[1/] Based on a computed recharge of 6.5×10^7 gallons/year and an accumulation time of 2 years.

Pumping tests conducted on wells drilled in Upper Sandy Member of the Gatesburg Formation that underlies the Gamelands site indicate that coefficients of transmissivity may approach 422,000 gpd/ft for the more productive portions of the aquifer (108). No attempt was made to compute water level buildups in this area due to the present small scale nature of the existing irrigation project at that site and the high coefficient of transmissivity values noted for these more permeable strata. Recharge effects would be obscured within this groundwater flow system because the Gamelands site is located above bedrock which serves to collect and drain groundwater along a zone of high permeability controlled by zones of fracture, thrust faults, bedding plane partings and sandstone and sandy dolomite strata that tend to have significant intergranular permeability. These sandy beds together with structural complexity facilitate groundwater flow, and localize solution cavities. A regional groundwater drain or low was apparent in 1963 within this area that parallelled bedrock strike or the outcrop trend of the Upper Sandy Dolomite Member (Figure 4). By 1965 this water table low became more pronounced (Fig. 5). By April of 1970 this drain extended for a distance of 10 miles beyond major springs on Spring Creek.

Benefits of Recharge

The test plots were selected with a number of factors in mind including the potential benefits that might accrue from increasing groundwater recharge. Wells within the principal Pennsylvania State University well field are located within 450 to 3000 feet of the Agronomy-Forestry test plots. Nearly 3.5 million gallons of groundwater a day are withdrawn from wells in this field and two wells located on campus. Water levels have continued to decline in response to increased pumping during the 1950's and 60's. Three new wells were added in the field since 1962 (UN-14, 24, and 26) and deeper pump settings are being used in these wells, water levels also declined under the influence of a prolonged drought (1962-1967) when nearly a 50 inch rainfall deficit was recorded (Fig. 117). During this period groundwater levels declined more than 80 feet within one of the major aquifers (Gatesburg Aquifer) in the region, largely due to the influence of the drought and continued groundwater discharge to major springs that were associated with this aquifer.

Water level declines during the period caused a reduction in yield of UN-17 and UN-24 (Fig. 118). UN-16 was abandoned due to its decline in productivity. Predicting the loss in yield that is likely to result in response to water level declines is a particularly difficult problem where fracture and solution void permeability predominates within an aquifer (108). This is especially true for the carbonate aquifers in the vicinity of the irrigation project where solution voids localized by bedding plane partings, joints, zones of fracture concentration and individual bedrock units account for most of the water obtained from wells. A decline in the water table of but a few feet can dewater one or more major water yielding openings with the result that the well may be rendered useless or experience a drastic loss in yield despite the fact that several hundred feet of water may still be standing in the well. This point is illustrated in Figure 118 for UN-24. This well yielded 450 gallons per minute when it was first drilled and the static and pumping water levels were at an elevation of approximately 975 and 920 feet. The yield declined to 100 gpm when the static and pumping levels fell to 940 and 690 feet. The relationship between water level and yield is not as clearly defined for UN-17.

Significant increases in groundwater recharge in the vicinity of this well field resulting in a stabilization of or rise in the water table will have beneficial effects. A new well (UN-26) was drilled in the area to take advantage of existing pipelines, powerlines, chlorination facilities etc. with the benefit that more water was obtained at a

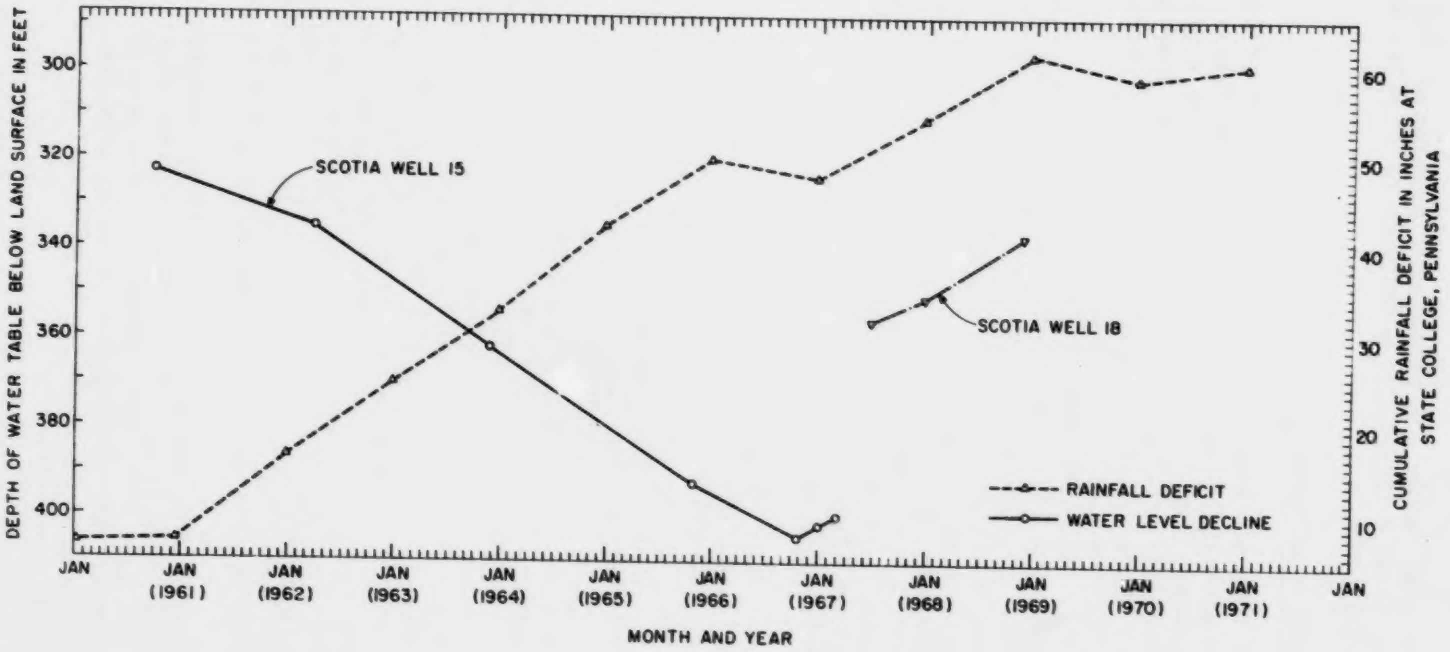

Figure 117. Rainfall Deficit and Water Level Decline Within the Gatesburg Aquifer Due to Natural Depletion.

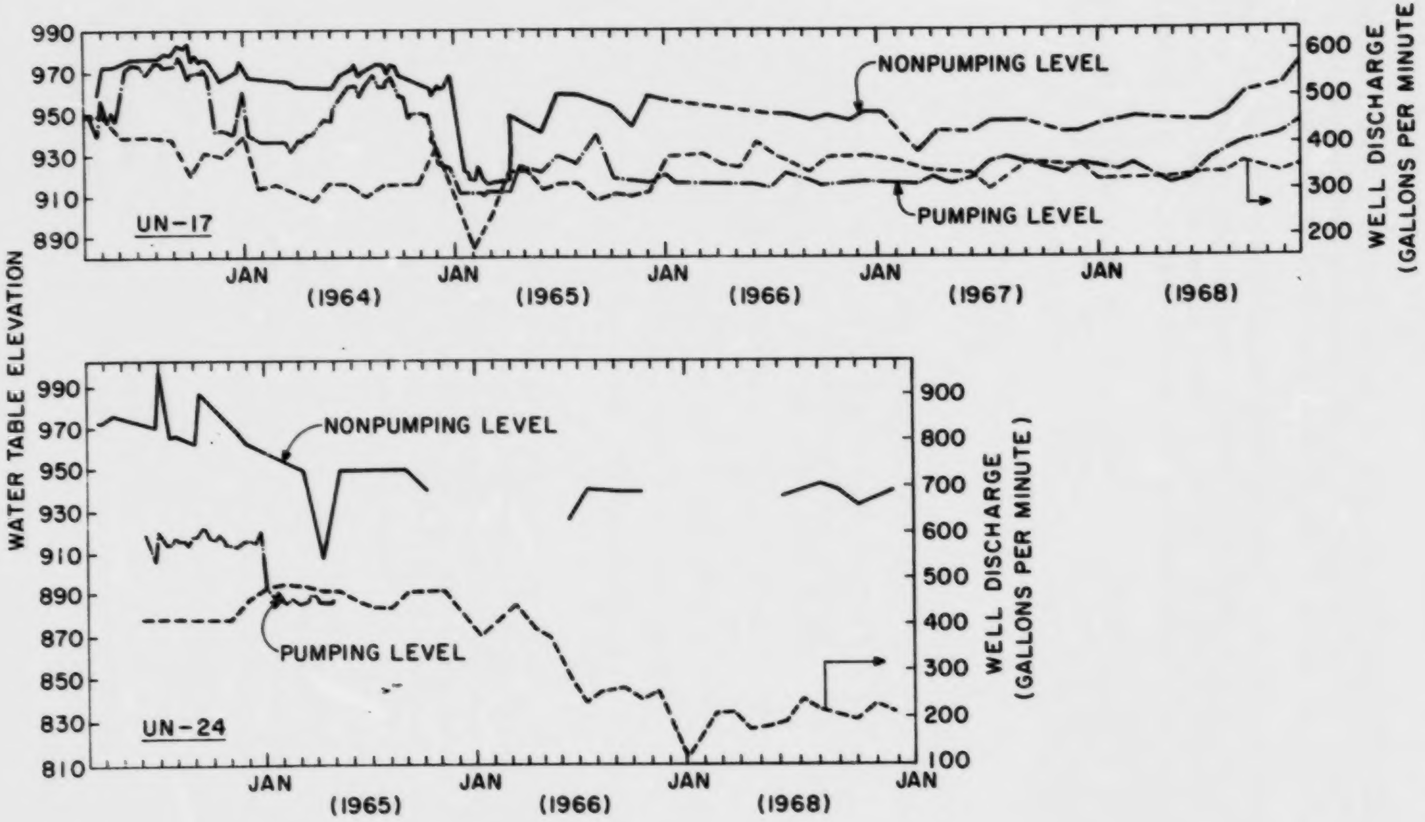

Figure 118. Pumping and Non-Pumping Water Levels Related to Decline in Well Yields Within the University Well Field.

lower cost than for the case if a more remote new well or well field had to be constructed. UN-26 has had a sustained capacity in excess of 1,000 gpm since it was placed into service in 1967.

Economies are also involved when production wells can be closely spaced. The cost of groundwater increases, among other factors, as the number of wells required to deliver a fixed volume of water increases, as pumping lift costs increase and as the spacing of supply wells increase.

Theis (106) for example, showed that the optimum well spacing in the simple case of two wells pumping at the same rate from a thick and areally extensive aquifer might be approximated by:

$$\gamma_s = 2.4 \times 10^8 C_p Q_d / RT \qquad (5)$$

Where:

γ_s = optimum well spacing, in feet

Cp = cost to raise a gallon of water 1 foot, consisting largely of power charges, but also properly including some additional charges on equipment, in dollars.

R = capitalized cost for maintenance, depreciation, original cost of pipeline, etc., in dollars per year per foot of intervening distance between production wells

Qd = pumping or disposal rate in gallons per day

T = coefficient of transmissivity in gallons per day per foot

A new well field to serve the Borough of State College (Water) Authority is being planned adjacent to the Gamelands irrigation site where an expanded 4.0 mgd irrigation system is being planned and designed. It is hoped that a 1 billion gallon a year or higher capacity well field can be developed in that area to take advantage of the more than 1 billion gallons of increased recharge expected from the expanded irrigation system.

Aside from helping to stabilize pumping levels, the increased recharge should decrease pumping lift costs within wells in the University well field and within the proposed State College well field.

Ackerman (109) has shown that the cost of pumping groundwater at any desired rate for a time period of an hour, day, week, 30-day month and 365-day year can be determined given the rate of pumping in gpm, the cost of electric energy in $/kw-hr, the total pumping head in ft, and the wire-to-water efficiency in percent given the following time factor constants:

Time factor	Constants
hour	6×10
day	1.44×10^3
week	1.008×10^4
month	4.320×10^4
year	5.256×10^5

The basic formula for theoretical horsepower is:

$$hp = Qwh/550 \qquad (6)$$

Where hp = theoretical horsepower (unit of work expressed as 1 hp = 550 ft-lb/sec).

Q = flow in cubic feet per second (cfs)

w = weight of water at 60 degrees F = 62.37 pounds per cubic foot (lb/cu ft)

h = total pumping head in feet (ft)

The actual power required in kilowatt-hours is:

$$\text{kw-hr} = 1.88 \times 10^{-4}\, Q_1 h\, t/E_o \qquad (7)$$

Where Q_1 = flow in gallons per minute (gpm)

E_o = wire-to-water efficiency in percent

h = total pumping head in ft

t = time in hours

A graphical relationship is provided by Ackerman that relates the kw-hr required to pump 1,000 gallons of water against a 100 foot head for any wire-to-water efficiency (E_o) in percent (Fig. 119). For a 50 percent wire-to-water efficiency, pumping costs would be \$0.00628.

For the case of a water supply well such as UN-14 or UN-24 to pump 500gpm against a 200 ft head with a 50 percent wire-to-water efficiency and a cost of electric energy of \$0.01 kw-hr, the power cost per year would be:

$$\$ \text{ per year} = \frac{1.88 \times 10^{-4} \times 500\text{gpm} \times 200 \text{ ft} \times 5.256 \times 10^5 \text{ min/yr} \times 0.01\ \$/\text{kw-hr}}{50 \text{ percent wire-to-water efficiency}} = \$3,950$$

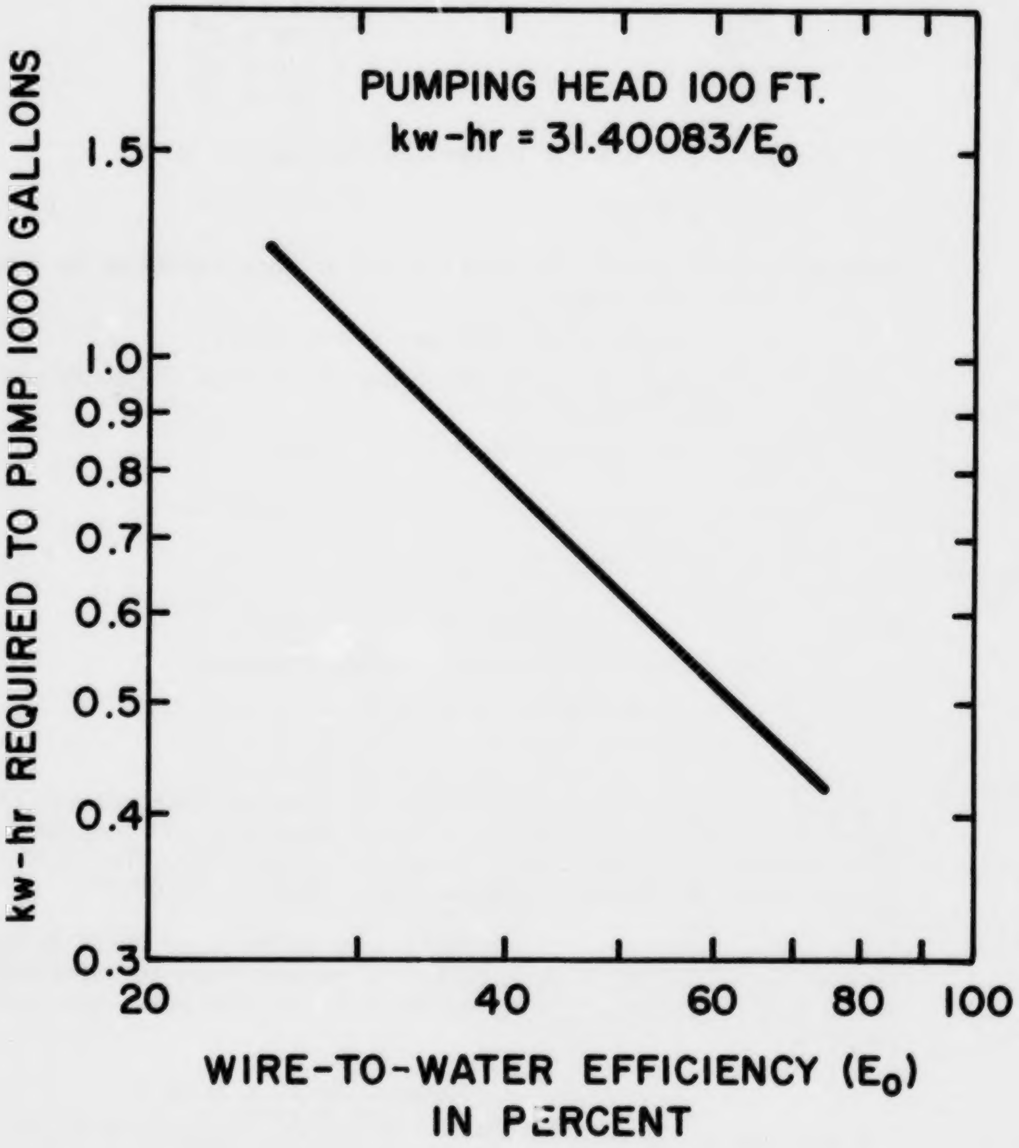

Figure 119. Power Requirements for Pumping 1000 Gallons of Water Per Minute at a 100-foot Head for Various Wire to Water Efficiencies (109).

Expressed another way, the annual cost of lifting 1 mgd 200 feet assuming a 50 percent wire-to-water efficiency and a power flat rate of 8 mills per kilowatt-hour would be $3,950. A 100 foot buildup in the water table could reduce the pumping costs to $1,975 per year for a 1 mgd well. If the water table were raised 100 ft a 4.0 mgd irrigation system located in close proximity to a well field such as the University well field could reap a $7,900 annual savings in pumping costs alone for a single 1 mgd well and up to $31,600 per year for a four well 4.0 mgd system.

SECTION IX

DESIGN AND COST OF SPRAY IRRIGATION WASTEWATER DISPOSAL SYSTEM

The purpose of this section is to review and summarize the various parameters affecting the design of a spray irrigation wastewater disposal system and on this basis to determine the annual cost of the system to the individuals residing in the community in terms of sewer service charges.

GENERAL CONSIDERATIONS

Distribution System

The distribution system is that portion of the spray irrigation scheme which actually delivers the water to the land. It consists of physical units such as headers, laterals, risers, sprinklers, and miscellaneous fittings. Its design necessitates the use of variables not normally used in wastewater treatment plant design. The following paragraphs describe the physical units, variables, and parameters which are associated with the design of a wastewater distribution system.

Units. The land on which the distribution system is located is a vital part of a spray irrigation scheme. Its physical and chemical characteristics affect many of the parameters used in the design and sizing of the units. The total land area to be irrigated is divided into a number of small plots, only a portion of which is under irrigation at any one time.

The wastewater is distributed on the land by means of a piping system consisting of sprinklers, risers, laterals, and headers. The sprinklers must be chosen, spaced and operated to provide uniform loading on all areas to utilize the total surface and obtain maximum renovation.

In order to allow an even distribution over a greater area, the sprinklers are attached to risers which elevate the sprinklers above thick vegetative ground cover. The risers are attached to laterals which constitute the greatest length of pipeline involved in the distribution system as there usually are several such lines on each header.

Variables. In designing a spray irrigation system for a specific daily flow from a wastewater treatment plant, four variables must be considered. These are weekly loading depth, hourly application rate, nozzle spacing and nozzle operating pressure. Each of these variables are independent, however, they are closely associated as described below and in the following section titled Parameters.

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The weekly loading depth determines the overall size of the distribution system. The loading depth usually is expressed in inches of wastewater applied uniformly over the entire disposal area each week. For a plant outflow of 0.5 MGD, 64.5 acres are required if the loading depth per week is 2 inches, whereas, if the loading depth is only 1 inch per week, 129 acres will be needed.

The hourly application rate, expressed in inches per hour, determines the size of plot that can be irrigated at any one time. Thus, for a 0.5 MGD system if the application rate is 1/4 inch per hour, approximately 3.1 acres will be irrigated at any one time, while if the application rate is only 1/6 inch per hour 4.6 acres will be required each time.

After the application rate has been determined, the choice of nozzle spacing establishes the number of sprinklers which will be operating at any one time. Let us consider the 1/4 inch per hour application rate which requires a 3.1 acres area. If we choose a 60' x 80' spacing, 28 sprinklers are needed to cover 3.1 acres. Had we chosen a 40' x 60' or a 80' x 100' spacing, 56 or 17 sprinklers would have been required.

The fourth and last variable is the operating pressure of the nozzles. With a particular nozzle the greater the pressure the farther the water will travel and the greater will be the emission rate, therefore the greater can be the spacing between sprinklers. Since the choice of pressure is affected so greatly by a number of parameters, it will be discussed more fully at the end of the following section.

Parameters. This section discusses some of the factors which must be considered in designing a spray irrigation system for a specific daily flow from a wastewater treatment plant.

The choice of weekly loading depth depends upon the renovation and hydrologic capabilities of the site relative to the quality of the liquid wastes applied. Most of the work using domestic municipal liquid wastes at Penn State was with an application of 2 inches per week. Very good renovation results were attained under agriculturally cropped areas at this loading with up to 100 inches per year. Certain industrial and cannery liquid wastes containing mostly organic particles may be applied at a much higher amount per week or per year and adequate renovation attained. Some industrial wastes, however, will require pretreatment to remove heavy metals and reduce certain salt concentrations before any may be irrigated.

The hydrologic capabilities of a site must be considered independently from the site's renovation ability. While sandy surface soils will permit high rates of application, the amount one can apply may be diminished by underlying tighter layers. Some of these soils can be drained to receive high loadings of liquid wastes while others cannot. Heavier soils covered with thick stands of vigorously growing hay crops may accept large amounts of water during the summer months, but may produce excessive runoff in early spring or late fall at these loadings. Effects of geology on the hydrologic regime of irrigated liquid wastes must be evaluated carefully.

An application rate of 1/4 inch per hour was used for most of Penn State's systems during the first five years. Most of the present system has been converted to 1/6 inch per hour. This lower application rate is preferable since one often must irrigate during and after heavy rains. Additional factors which affect the rate of application include: the soil texture, structure, and permeability; the soil cover crop and management procedures; the surface topography; and the climatic conditions.

The choice of spacing between sprinklers is associated closely with both the application rate and the amount of pressure at the nozzle. The primary factor which affects the choice of spacing is the vegetative cover -- open field crops or woods. As discussed under Irrigation Application Systems in Section IV on Methods and Materials for Penn State's solid-set system, an 80' x 100' spacing was preferred for open fields and a 60' x 80' spacing was recommended for wooded areas.

The prevailing direction and intensity of winds affect the uniformity of application, particularly at the wider sprinkler spacings. As the spacing is increased, the height of the spray stream must be increased according to the laws of projectile motion. As the top of the spray stream arc becomes higher the wind has a greater distorting effect on the distribution pattern. Thus, wind breaks often become an integral part of the irrigation distribution system design.

The nozzle pressure and diameter are chosen such that the appropriate rate of application can be distributed uniformly over the specified spacing between sprinklers. A pressure of 48 psi will cause 8.3 gpm to flow from a 13/64 inch diameter nozzle. This would be appropriate for a 1/6 inch per hour application rate on a 60' x 80' spacing. For a spacing of 80' x 100' and an application rate of 1/6 inch per hour, 58 psi applied to a 1/4 inch diameter nozzle would give 14 gpm which is an appropriate design.

While the above discussion of application rate, nozzle spacing, and nozzle operating pressure is appropriate for the design of a solid-set irrigation system; it is not adequate for the designs of other irrigation systems as: the center pivot, the giant gun, the traveling gun, and various other self-propelled or hand moved systems. Frequently one of the above type systems is just as appropriate as the solid-set system and usually is much more economical. In most of Pennsylvania, however, the geology, topography, and tree cover encourage the use of solid-set systems. The solid-set arrangement is the only one discussed in this report.

The physical features of the land, in addition to affecting the variables, also directly affect the design and cost of the entire system. The total head requirement for the system is directly dependent upon the difference in elevation between the pumping plant and the distribution areas; as well as the friction loss in the transmission and distribution lines, and the pressure requirements of the sprinkler heads.

Design for a rough, undulating terrain, of course, is more complicated than for a gently sloping area because of static head changes and more importantly the need for draining all lines during periods of freezing conditions. The rougher the terrain the more difficult this becomes. The number of drain locations should be kept to a minimum to reduce labor and to permit more efficient management.

The configuration of the field frequently is determined by the availability of land. Excess lengths of pipe and inefficient distribution system arrangements often are required due to unavailability of large, contiguous areas.

The variations inherent in the variables and parameters are exceedingly great. Thus, to present a generalized design which applies to all situations would present an almost insolvable problem. The cost analyses in this report is for one particular design. Costs for other designs may be computed from graphs and nomographs in Allender's thesis (110). In presenting design procedures in subsequent sections of this report, an attempt will be made to use representative limits but these limits must be reviewed with the preceding discussion in mind.

Transmission System

The transmission system which delivers the water to the distribution system, includes the remaining facilities involved in the spray irrigation scheme. The individual unit's design for the transmission system is dependent mostly on the waste's physical and chemical characteristics. The procedures commonly are encountered in the design of more conventional treatment schemes. The units usually involved are: screens, a flow equalization tank or lagoon, pumps, pipeline and a centralized control system. These units are required in nearly all systems and are further defined in the following paragraphs.

Units. A control system will have to be provided for the wastewater pumps. This system will be quite simple if no control over the sprinkler system is needed, but, as the desired automation of the sprinkler system increases, the required control system becomes more complex. Automation of the sprayfield can vary from automatic or remote valve operation to a completely automated system. This latter system could involve such items as pressure indicators, devices to allow drainage of individual lines and automatic control of valves to allow irrigation fields to be placed in or out of operation. Even further automation could allow an automatic tabulation of fields irrigated and could provide a sequence to prevent irrigation of a single field more than once per week.

Any wastewater effluent contains suspended solids. The size of these solids and the frequency with which they are encountered are a function of the efficiency of the treatment plant. These solids, which are not normally considered an effluent disposal problem, can cause clogging of the nozzle orifices and must be removed. This removal is accomplished most easily by use of screens which can be cleaned continuously.

As implied previously, the number of acres to be irrigated each time and the application rate establish the instantaneous flow rate to the distribution system. Thus, if separate pumping facilities for peak loads are not desired, any variation in the effluent flow over a year's time must be distributed over this time period to allow an even flow rate to the fields. This even distribution can be accomplished only by means of an equalization tank or lagoon which allows the waste to be stored at times of excess flow until times of minimum flow.

Delivery of the waste effluent to the distribution field must be at a guaranteed pressure. Thus, pumps capable of delivering the desired flow at the desired distribution field pressure must be provided. Pump discharge pressure also must be sufficient to overcome static differences in elevation, plus pipeline losses.

The transmission pipeline is, of course, a force main discharging from the pumping station and should be designed as such.

As in the distribution system, the transmission system units are affected by items which will be considered as both variables and parameters.

Variables. The only true variable is the transmission pipeline diameter. Diameter variation will affect both the cost of the pipeline and the pump discharge head. The pipeline cost is a direct function of it's diameter while the pump size and power requirements are an inverse function of the pipe diameter.

The sprinkler nozzle size like the operating pressure, most likely will be determined in the distribution system design. However, it determines the screen hole size or vice versa as the screen must be slightly smaller than the nozzle size.

Parameters. The type and size of the units within the transmission system are determined mainly by the parameters; effluent solids, flow characteristics, sprayfield elevation and location, and soil type. All the parameters will differ from one installation to another but once determined for an individual area they will remain fairly constant.

SYSTEM DESIGN

In order to estimate the cost of a spray irrigation system, it is first necessary to make a preliminary design of the system. As each system must be designed individually, the preliminary design information cannot cover all situations and the final design should be done by a competent engineer. However, this information will serve to provide a design sufficiently detailed so that an accurate preliminary estimate of costs can be made. This preliminary design information will be presented in two parts: the distribution system and the transmission system.

Distribution System

In designing the distribution system the following items must be determined: the number and type of sprinklers, the number of risers and unions, the length, size, and number of laterals, the length and size of the header, and the number of valves. Since these items will be similar over the entire area of the distribution field, the methods presented will give the required number and lengths of these items per acre.

The actual graphs, tables, and nomographs used in the calculations, as well as explanations of their use are described in Allender (110).

The system is developed from the sprinkler spacing as the first variable. The parameters affecting this variable have been discussed previously and it is necessary now only to set the upper limits for the spacing. Maximum spacing between laterals of approximately 80 feet in woodlands provide satisfactory distribution of effluent at reasonable costs when using solid-set systems. Since the number and size of the other distribution system units are both inversely and directly proportional to this variable, an optimum value at which costs will be a minimum should exist for open fields where larger spacings can be used. This relationship will be discussed at greater length in a later section.

The operating pressure and application rate must also be determined prior to the distribution system design. Operating pressure has both lower and upper limits which are determined by the nozzle selected. The lower limit is set by the minimum pressure necessary to operate the sprinklers and adequately cover the spacing. This value differs according to the sprinkler chosen but in most cases it will be between 40 & 50 psi for a 60' x 80' spacing. The upper limit, likewise, is determined by the sprinkler type and is limited by the point at which an even distribution is no longer possible. Pressures in the range of 50-65 psi ordinarily are used for a spacing of 80' x 100'.

The permissible application rate will differ according to the physical parameters existing in any one area. In the Penn State study application rates of 1/6 and 1/4 inch per hour were used. The hourly application rates were chosen sufficiently low to insure infiltration even if heavy soil and wet conditions are encountered.

Work at Penn State indicated that with a weekly application depth of four inches excessive quantities of some of the waste constituents were found in the water after it had passed through the soil. In a poll of seven industries in Pennsylvania using spray irrigation (111), three industries using loading depths between 21 and 37 inches per week either reported a runoff problem or allowed runoff and discharge. The four industries reporting no runoff problems were using application depths within the 2 inch per week limit of the Penn State study and it is believed that this limit is a fairly reasonable value. Most of the figures presented in Allender (110) are thus based on these values but some latitude was allowed for choice of other values.

A loading amount of two inches per week and an application rate of 1/6 inch per hour were chosen as preferred values under Penn State conditions. These satisfied the physical parameters and required a reasonable amount of labor to operate the system. For instance, at 1/6 inch per hour and two inches per week the irrigation system need be changed only once every 12 hours while at 1/4 inch per hour the irrigation plots must be rotated every eight hours.

After compatible nozzle spacings, operating pressure, and application rate have been established, the remainder of the distribution system can be designed.

The amount of land needed for the irrigation field is a major item and should be the first concern. The number of acres necessary can be found from the daily flow and the weekly application rate using Figure 120. Enter with the weekly loading depth, 2 in/wk (Pole A) and the daily flow, 1 mgd (Pole B) and read the area requirement where the resulting line intersects Pole C. To obtain the total cost pivot on Pole C to the cost/acre (Pole D) and read the total cost where the resulting line intersects Pole E.

It is necessary to have the spacing less than the effective distribution diameter to allow overlapping of the streams and give an even application. Several spacing arrangements and procedures are illustrated in Figure 121 and the relation between effective distribution diameter and required sprinkler spacing is given in Figure 122. The number of sprinklers and risers needed per acre is a function only of the type spacing and can be determined by use of Figure 123.

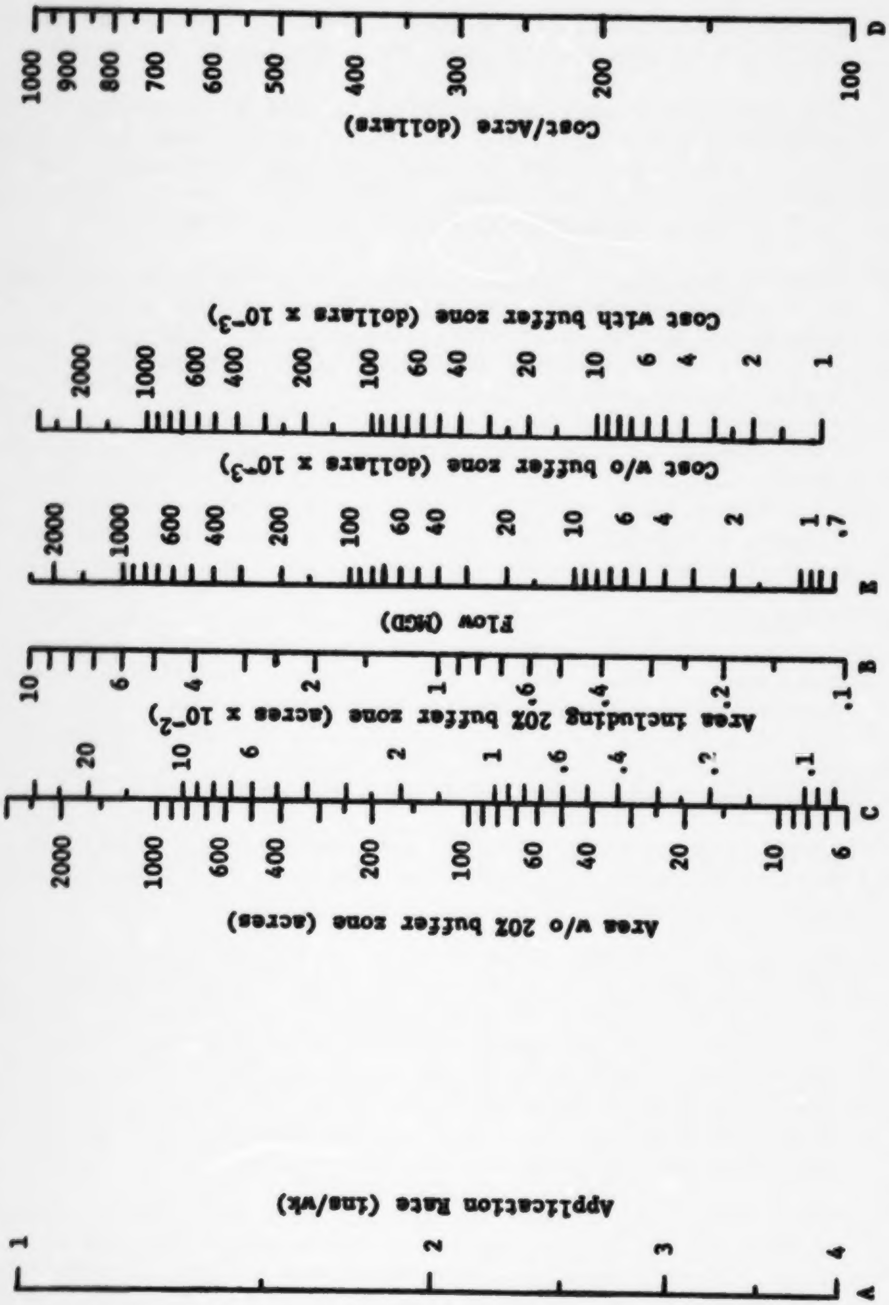

Figure 120. Land Requirements and Costs with and without a Buffer Zone Related to Daily Flow and Application Rates.

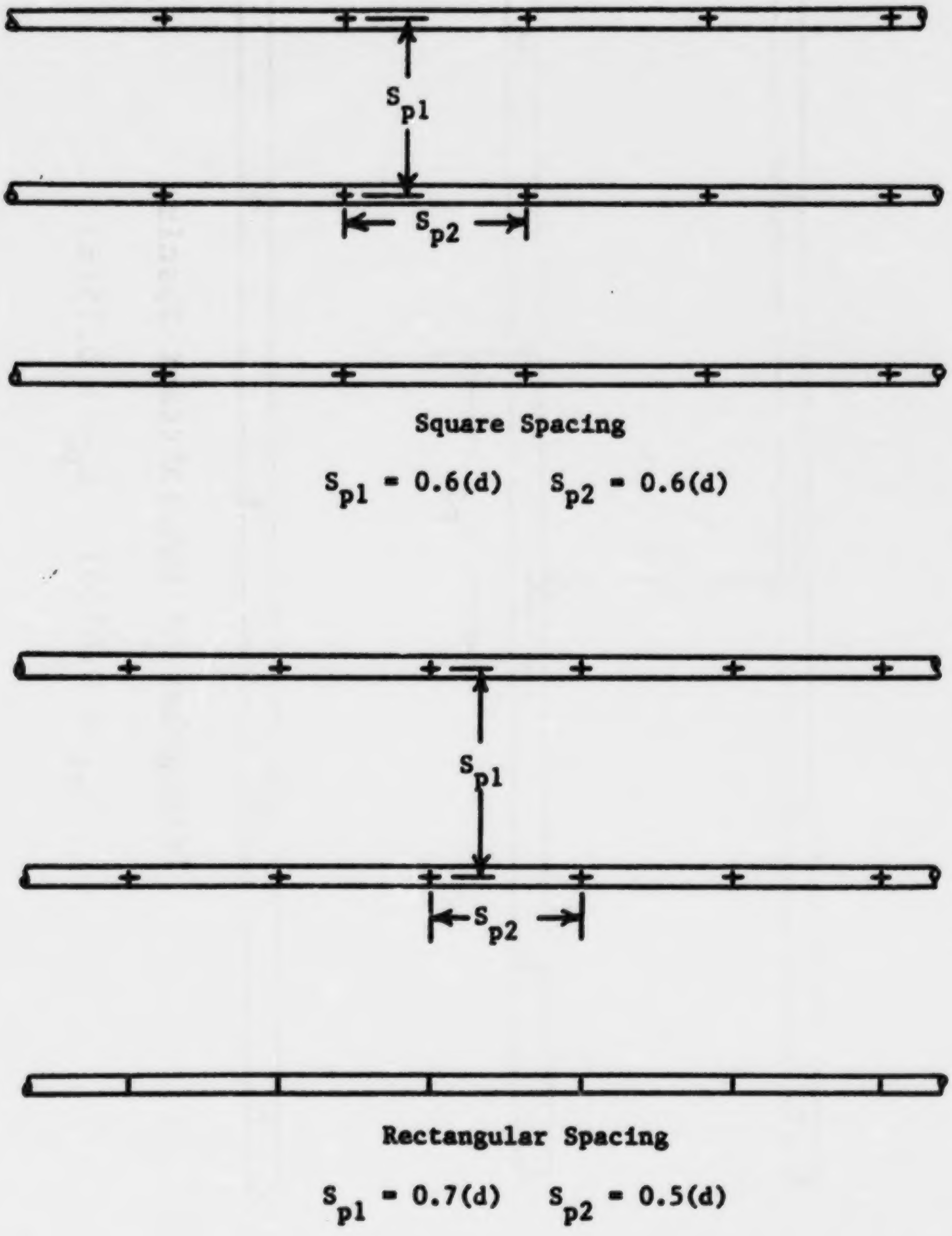
S_{p1}
S_{p2}
Square Spacing
$S_{p1} = 0.6(d)$ $S_{p2} = 0.6(d)$
S_{p1}
S_{p2}
Rectangular Spacing
$S_{p1} = 0.7(d)$ $S_{p2} = 0.5(d)$

Figure 121. Sprayfield Sprinkler Arrangements.

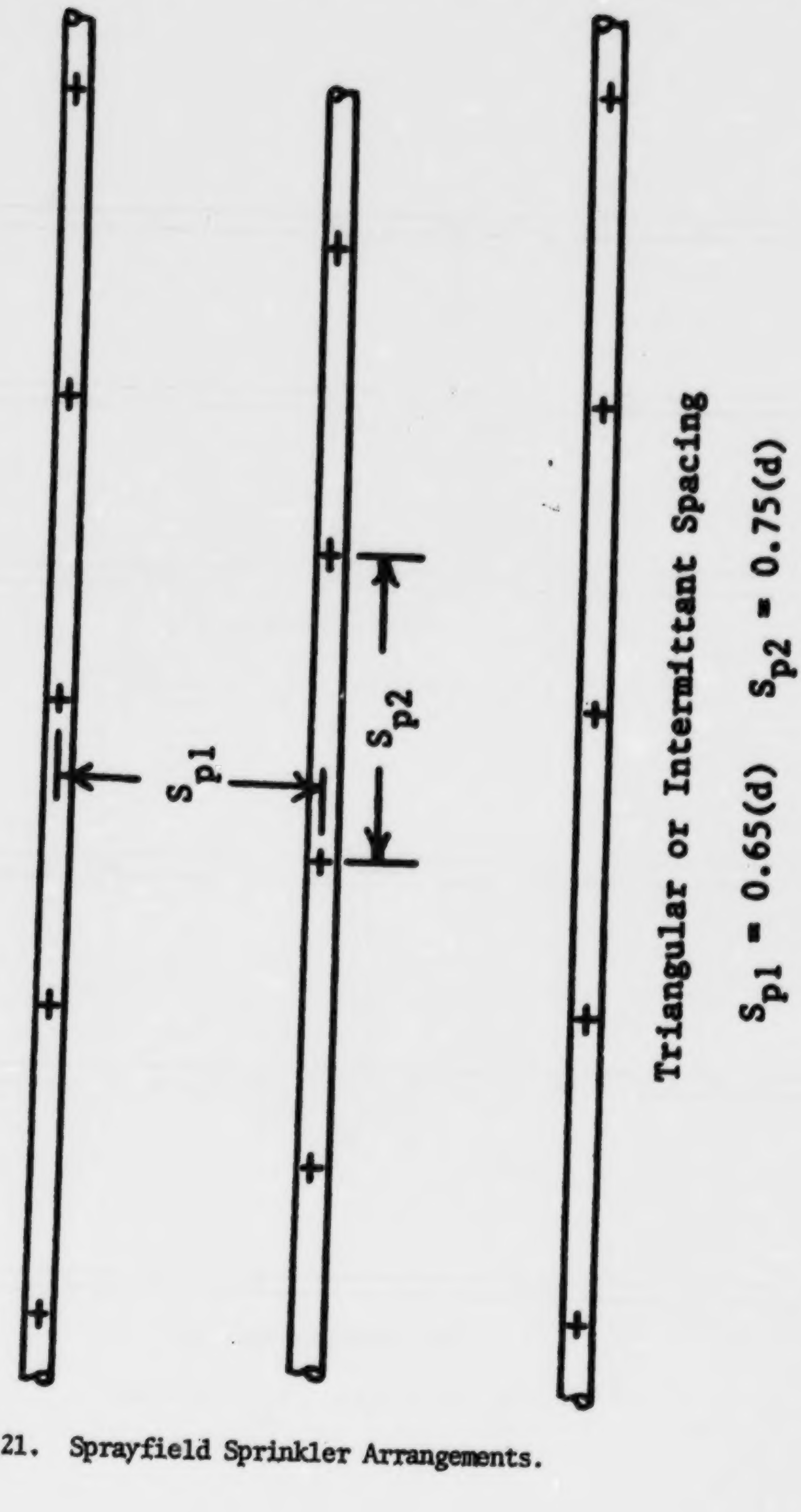
S_p1
S_p2
Triangular or Intermittant Spacing
S_p1 = 0.65(d)   S_p2 = 0.75(d)

Figure 121. Sprayfield Sprinkler Arrangements.

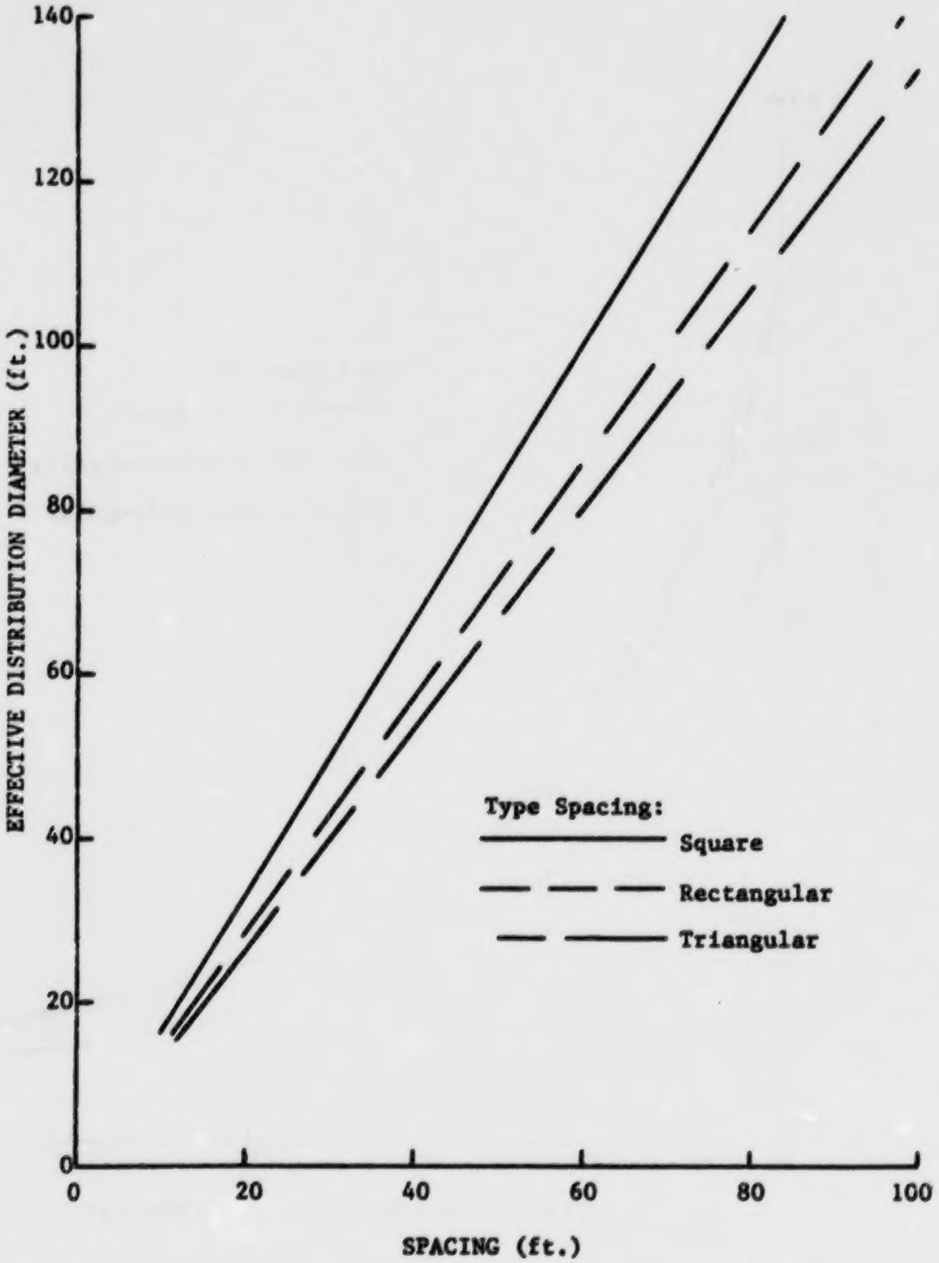

Figure 122. Required Sprinkler Separation Distances in Relation to Effective Distribution Diameter with Three Types of Spacing.

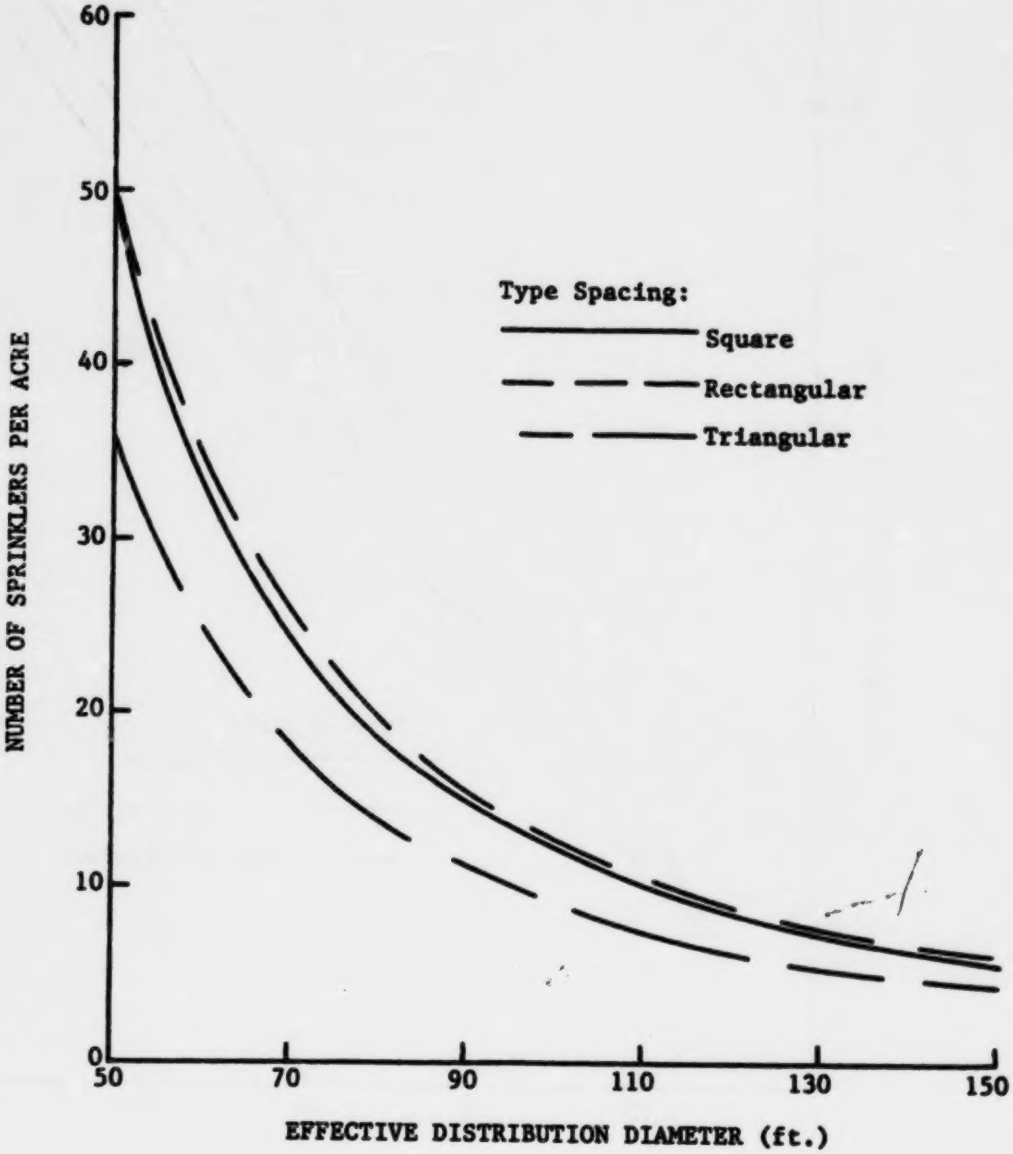

Figure 123. Number of Sprinklers per Acre in Relation to Effective Distribution Diameter with Three Types of Spacing.

Once the number of sprinklers to be used are determined, the type of sprinkler can be chosen. Each manufacturer has several models available and each model can be varied by changing the nozzle orifice size or the inclination of the nozzle with the horizontal. Tables are usually presented by the manufacturer which give the effective distribution diameter and the individual sprinkler discharge as a function of the operating pressure and the nozzle hole size for each model. The model, nozzle hole size, and operating pressure must be determined by use of the effective distribution diameter and the nozzle flow. The nozzle flow can be obtained from Figures 124 and 125 for 1/4 and 1/6 inch per hour application rates. Figure 126 allows the reader to convert that result to a discharge rate for any other hourly application rate.

The length of lateral pipeline required is a function of the spacing and the sprinkler configuration scheme and can be found for one acre by use of Figure 127. This figure again uses effective distribution diameter instead of spacing distance so that differences due to the positioning of the sprinklers can be shown.

After the length of pipeline is determined, its diameter can be determined from the allowable headloss in the field. A pressure difference between the ends of a lateral of no greater than 20% of the maximum operating pressure frequently is recommended. This 20% pressure variation produces only a 10% volume variation which is quite acceptable. Since pressure change is realized as both static (elevation) changes and friction losses, not all of the pressure difference can be assigned to friction loss within the header and laterals. Pressure changes due to elevation differences must be determined prior to assigning an allowable headloss to the laterals and header. The headloss in the header should be assigned first and will be discussed later. Since all laterals are assumed to have equal flow only one lateral need be considered in determining the allowable diameter. The lateral flow can be obtained from Figure 128 and the individual lateral length can be obtained from Figure 129. Figure 130 is a nomograph from which the allowable pipe diameter can be obtained.

Figure 128 assumes the total flow will be applied to one irrigation plot at any particular time. If more than one plot is used, the flow given by the nomograph will have to be divided by the appropriate number. The nomograph is used as follows: enter with the daily flow (Pole A) and the hourly application rate (Pole B); pivot on Pole C to the proper side dimension ratio, the ratio of the field dimension perpendicular to the laterals (width) to the field length (Pole D); and read the lateral flow where the resulting line intersects Pole G.

Figure 129 also assumes that only one plot will be used at any one time and if more are used the lengths will have to be reduced accordingly. The nomograph is used as follows: enter with the daily flow (Pole A)

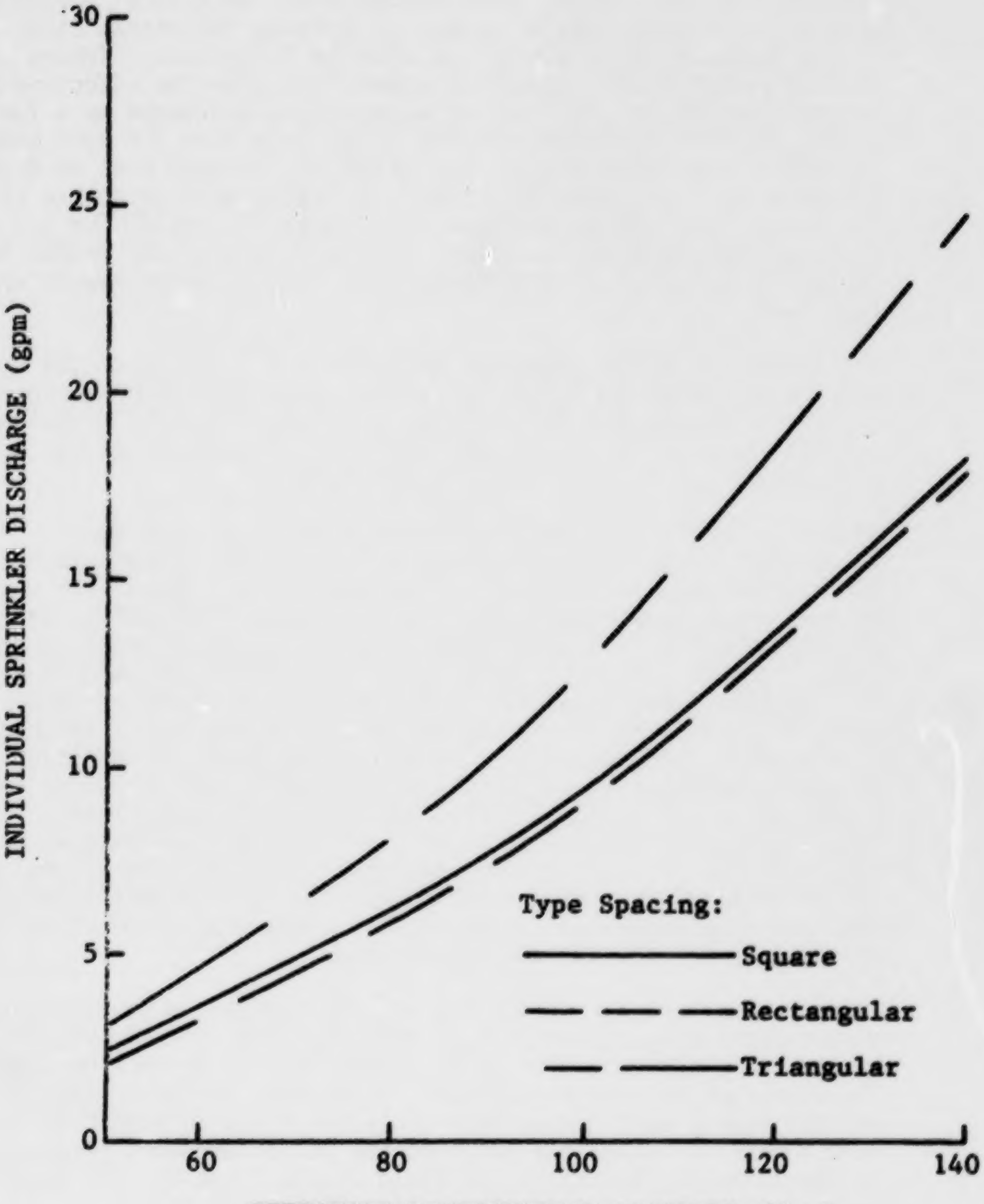

Figure 124. Sprinkler Discharge for Various Effective Distribution Diameters and a 1/4 Inch per Hour Application Rate.

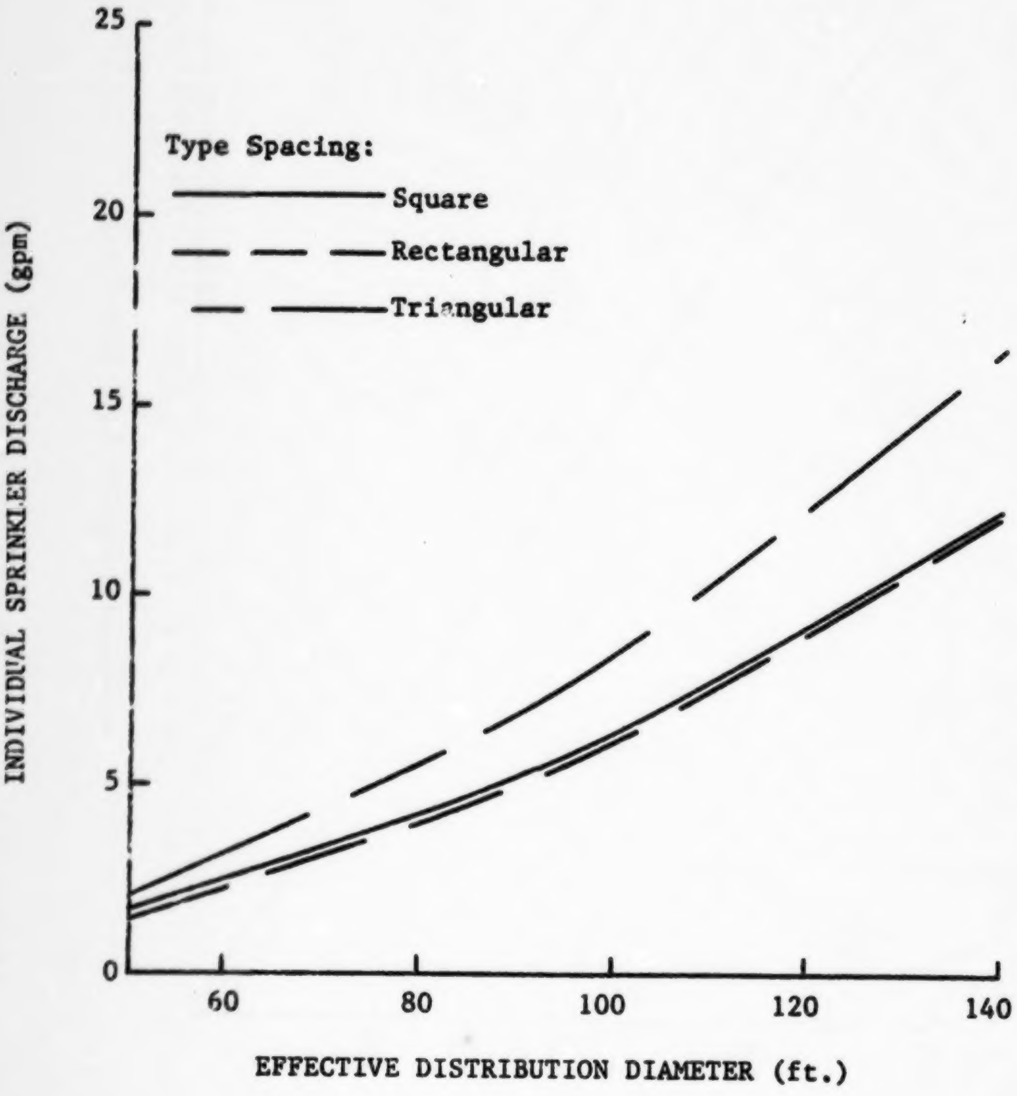

Figure 125. Sprinkler Discharge for Various Effective Distribution Diameters and a 1/6 Inch per Hour Application Rate.

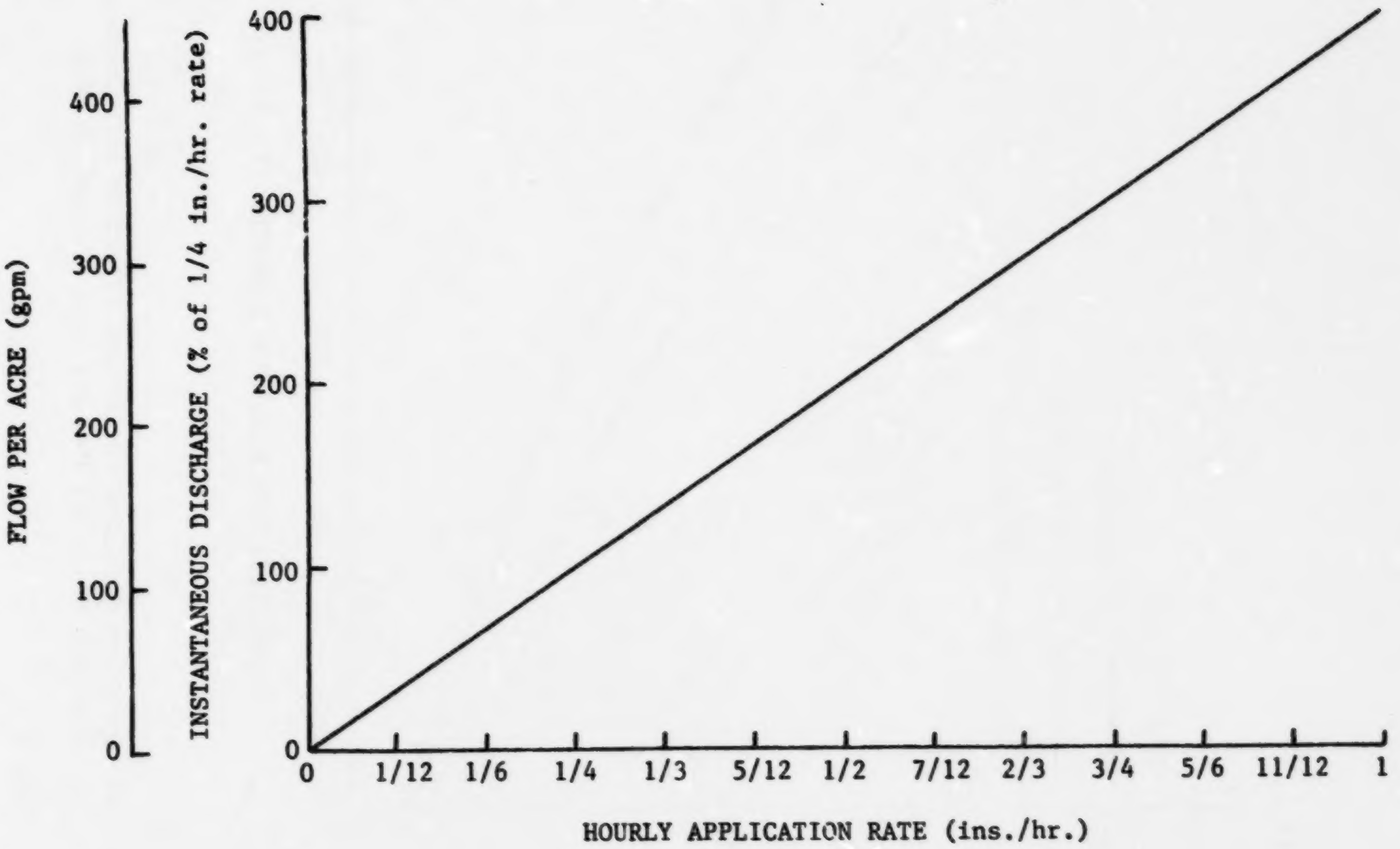

Figure 126. Instantaneous Discharge (gpm/acre) for Various Application Rates.

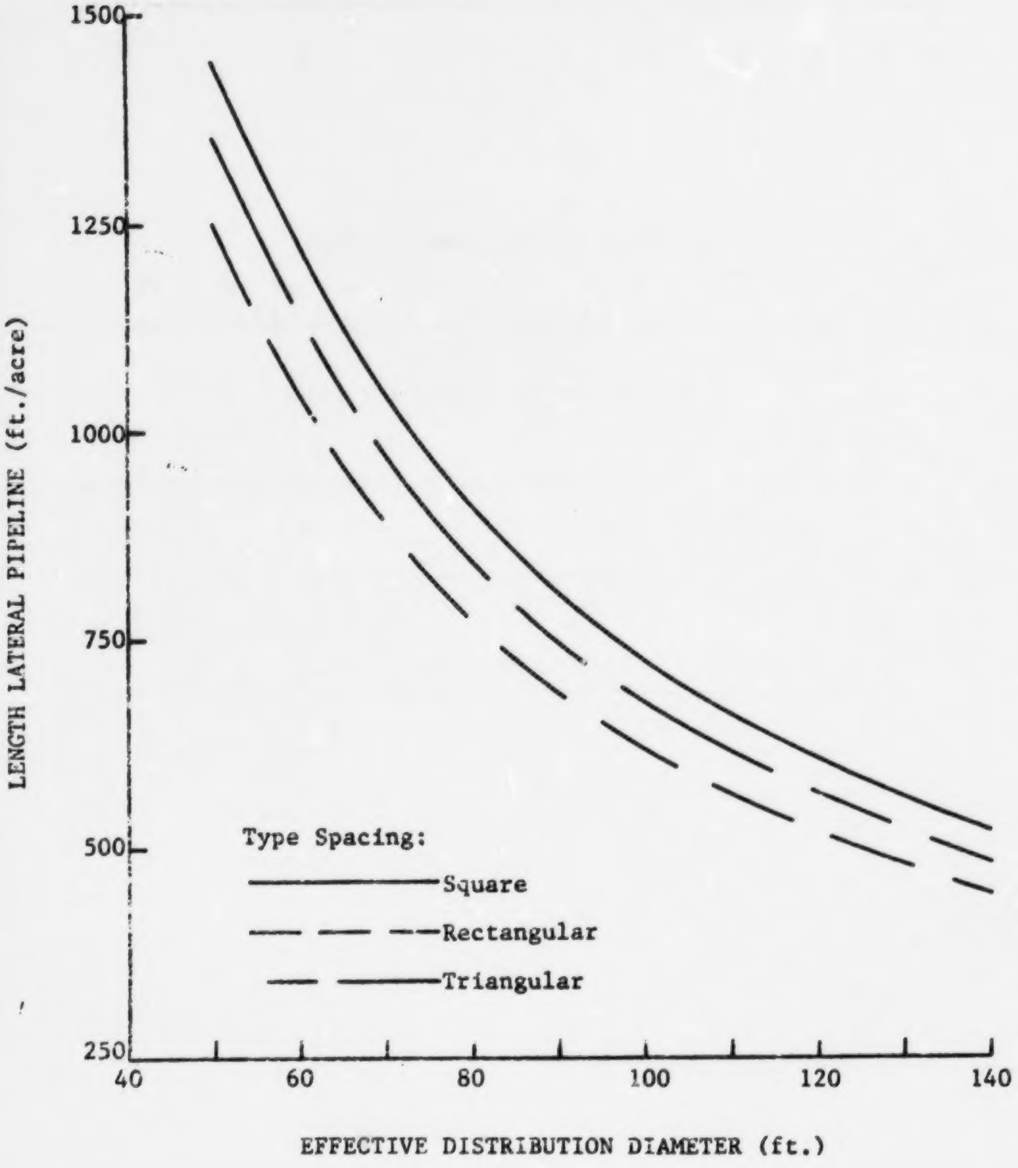

Figure 127. Required Lengths of Lateral Pipeline for Various Effective Distribution Diameters.

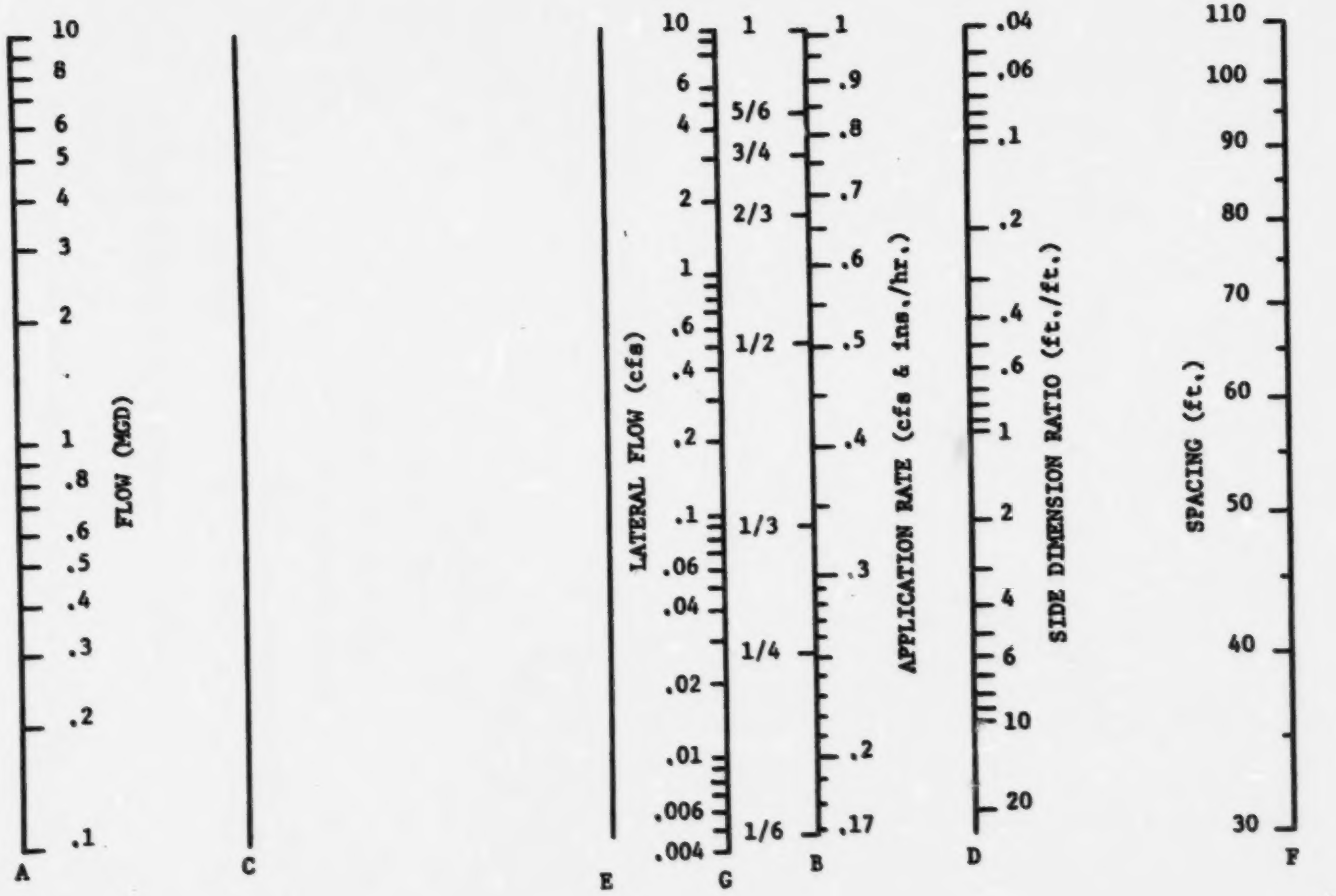

Figure 128. Lateral Flow in Relation to Daily Flow, Application Rate and Side Dimension Ratio of the Irrigation Plot.

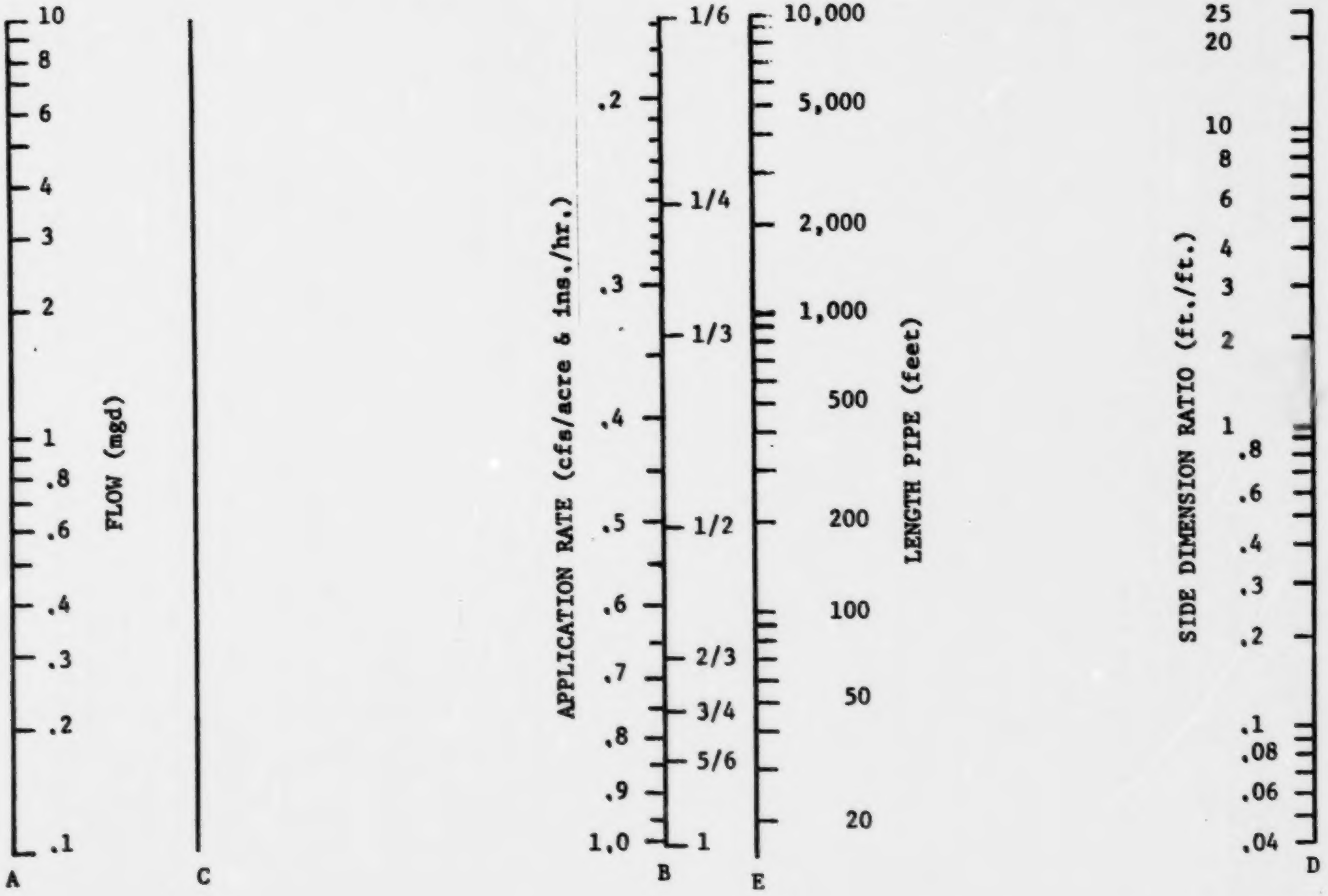

Figure 129. Required Lengths of Lateral Pipeline in Relation to Daily Flow, Application Rate and Side Dimension Ratio of the Irrigation Plot.

and the hourly application rate (Pole B); pivot on Pole C to the proper side dimension ratio (Pole D) and read the lateral or header length where the resulting line intersects Pole G.

The header length, like the individual lateral length, can also be determined from Figure 129. The diameter of the header can then be determined in the same manner as that for the lateral. Its value and the length of line to be sized will depend on the point at which the water is introduced to the header. In most cases it should be at the one-half point to allow only one half the total flow in any one length of pipe at any one time.

Figure 130 allows the appropriate pipe diameter to be found using the pipeline flows and lengths found in Figures 128 and 129, the sprinkler operating pressure, and the allowable headloss. This nomograph is used by entering with the pipeline lateral or header flow (Pole A) and the pipeline length (Pole B); pivoting on Pole C to the operating pressure (Pole D); pivoting again on Pole E to the proper percentage (Pole F) and reading the diameter from Pole G. The right side of this pole is to be used for flows between 0.1 cfs and 10 cfs while the left side is to be used for flows between 10 cfs and 1000 cfs. Flows less than 0.1 cfs are not presented as even under maximum conditions the required diameter would not exceed four inches.

Once the number, length and size of units are determined for an acre, the total numbers and lengths can be found by multiplying by the total number of acres required for the entire system. The total number of acres required can be found by use of Figure 120. This nomograph was constructed for determining land costs but the area in acres is available as an intermediate value. There will be little if any variation in the land requirement for identical average daily flows. Even in systems where some of the effluent can be sold to outsiders for irrigation purposes, an area equal to that determined above will be required. Sufficient area must be provided for seasons during which there is little or no irrigation sale.

Transmission System

For a preliminary design of the transmission system it is necessary only to determine the headloss in the transmission line, its diameter, and the capacity of the equalization lagoon and pumps.

The headloss in the transmission line can be determined in two ways: first by assigning a specific headloss to the pipeline and using Figure 131 to determine the pipe diameter or by choosing a pipe diameter and finding the headloss from Figure 131. This last figure gives the headloss per 100 feet for different flows and pipe sizes. Either of the above methods allows for optimization of one of the two major cost items (power costs and pipeline costs) but neither considers both.

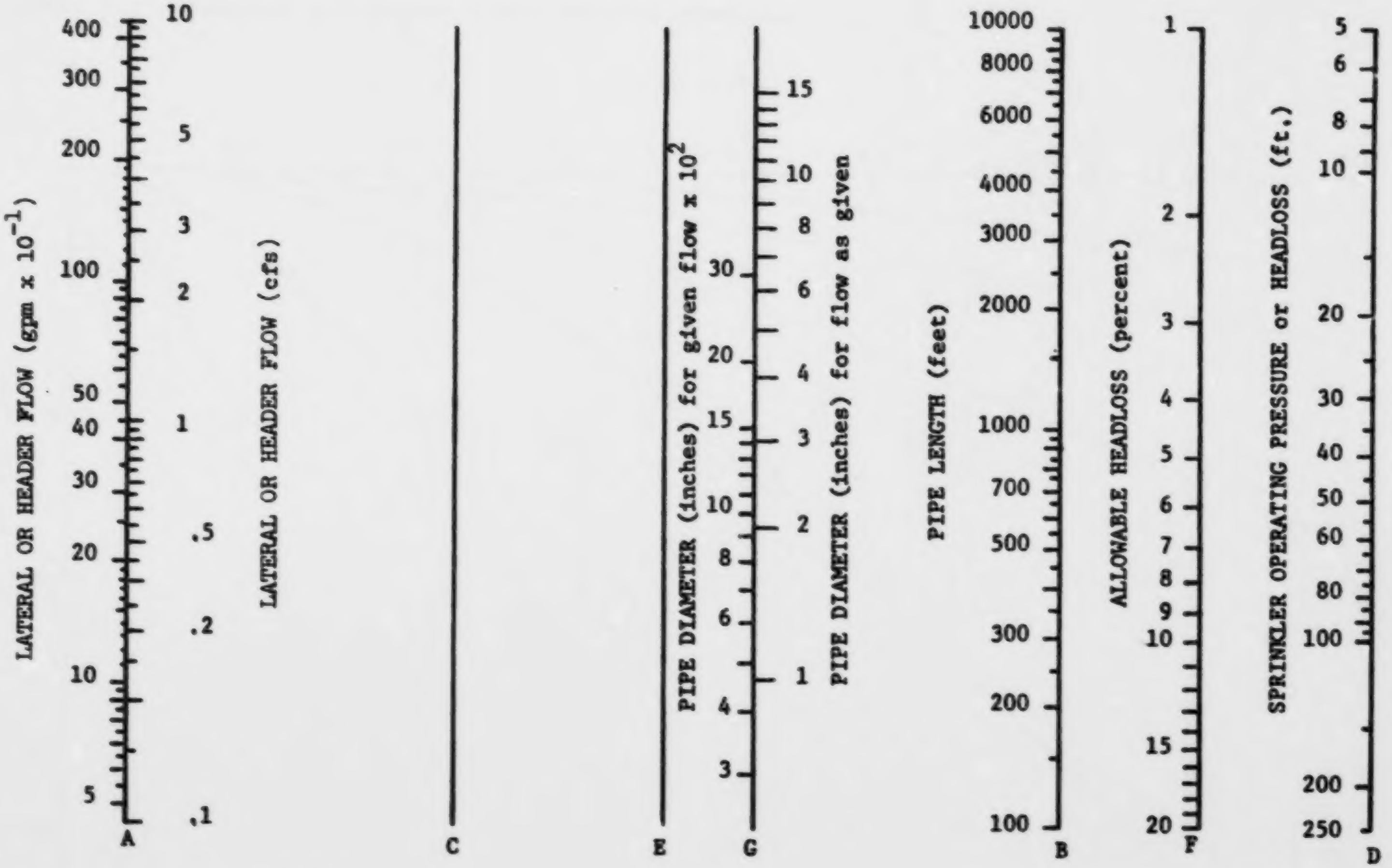

Figure 130. Lateral or Header Diameters for Various Lateral or Header Flows as Related to Pipe Length and Allowable Headloss.

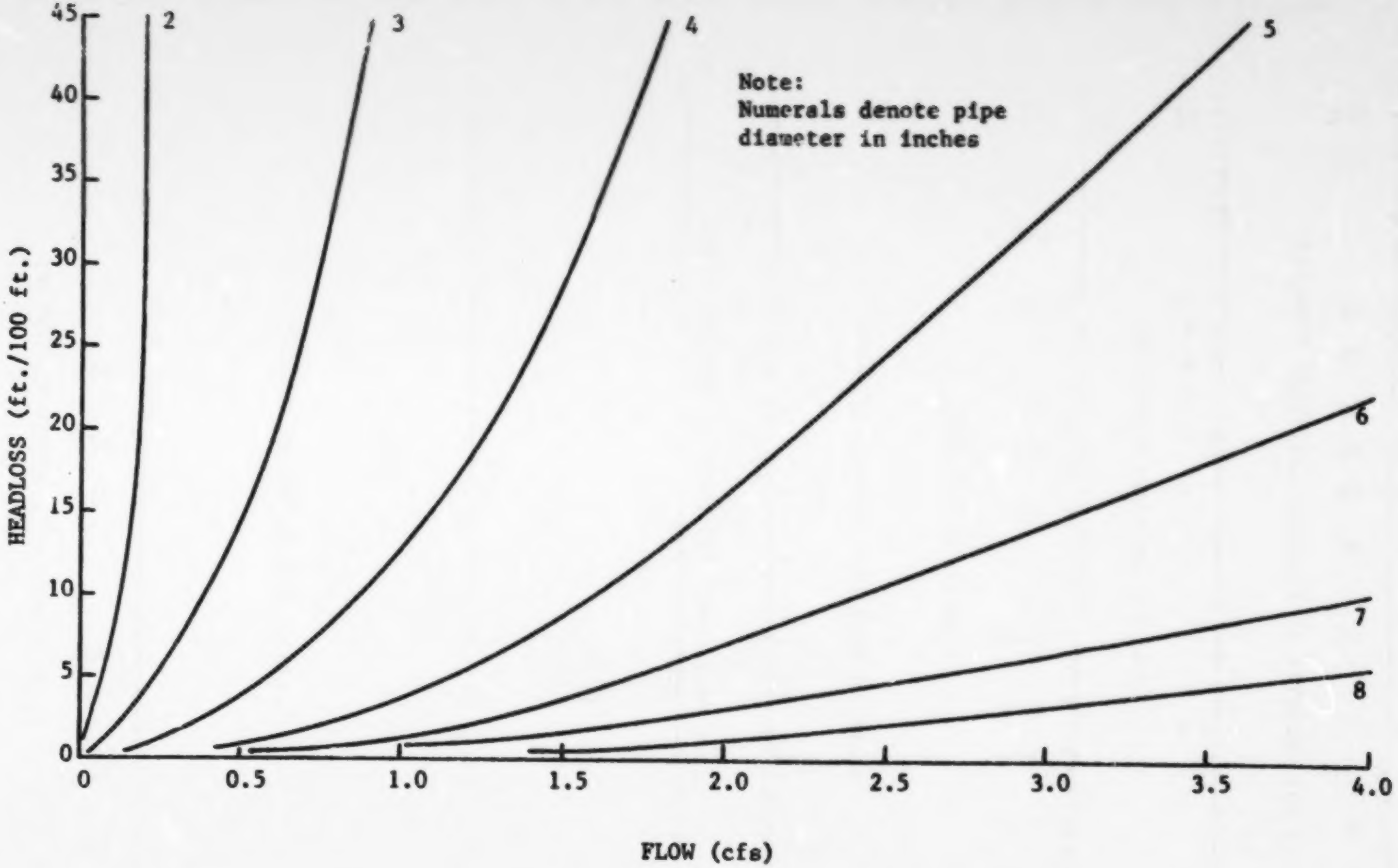

Figure 131. Headloss for Various Flows and Pipe Diameters.

Under the section discussing costs, presented later, both will be considered and an optimum pipe size determined for the various flows. This pipe size can then be used along with Figure 131 to determine the expected headloss.

To balance the normal flow variations experienced in each individual sewerage collection system against the daily pumping capacity several alternatives may be employed. One of these would be to provide an equalization lagoon with a capacity large enough to store the excess flows above a uniform daily pumping capacity over a time period long enough to be counter balanced in total mass by the deficiencies in flow below that uniform daily pumping capacity. This time period was computed in 1968 for six sewerage systems in Northwestern Pennsylvania and is expressed in Table 164 in terms of storage needs as a percent of the average daily flows. The values ranged from 1700% to 6400% with an average of 4000%. The latter value was used and it was assumed that a storage lagoon with a capacity equal to 40 times the average daily flow must be provided.

Table 164. Effluent Storage Needs.

Item	A	B	C	D	E	F
Average Daily Flow (MGD)	.291	.447	.533	1.035	1.205	2.60
Storage Needs (% of Average Daily Flow)	5500	3100	3900	6400	3800	1700

A substantial reduction in the size of the equalization lagoon may be possible by utilizing the inherent range in pumping capacity of any pump and by balancing temporary increased loads on a particular portion of the irrigation site with equivalent decreased loads at some other time.

If an equalization lagoon is not provided, the transmission and distribution system must be sized to handle the weekly variations in flow if the irrigation cycle is a weekly one. Such a system may have to include additional land for irrigation or allow for temporary increased loading during periods of high flow, pumps with controllable variable speed or a standby supplemental pump to provide increased capacity, an oversized transmission line, and more intensive management.

SYSTEM COSTS

The net cost of effluent disposal by spray irrigation is dependent upon the system required to do a specific job, at a specific location, at a specific time, as well as the procedures adopted for management of the spray field. Since different situations require different designs and management procedures, no general overall cost information can be given.

Based on certain assumptions used by Allender (110) the estimated cost of hypothetical systems carrying flows of one, five and ten million gallons per day (MGD) will be presented. The assumptions may or may not fit another specific situation but they will serve as a basis for a rough cost estimate under what can be regarded as moderate parameter levels. The costs will be discussed under the general areas of capital costs of the pumping system and delivery system, and operation costs. Engineering and contingency costs were estimated at approximately 10% of other capital costs and maintenance and contingency costs at approximately 10% of annual operating costs.

Pumping System

It is assumed that the system will be pumping secondary treatment municipal wastewater and that an equalizing storage pond with a capacity forty times the average daily flow will be needed to insure a more or less constant pumping rate.

The pumping station is a typical wastewater station with the usual stand-by pump and discharging into a force main. Also included is a screening system before the pump station to prevent clogging of the sprinkler nozzles.

Delivery System

In this computation the delivery system includes a one mile transmission pipeline (force main) and the spray field itself, including land and the distribution system of sub-mains, laterals, sprinklers and fittings.

The estimates include the purchase of land at $140 per acre, the average cost of land in 1964 in counties in Pennsylvania with less than 5% urbanization. In counties with more than 10% urbanization the average cost was $680 per acre. The amount of land required is based on a total application of two inches per week at an application rate of one-sixth inch per hour. The land is assumed to be open fields rather than forest. Land survey and site preparation costs are also included.

The force main is one mile long with a 200 ft elevation lift. This distance is probably short for many larger installations, but may be quite appropriate for the small system where this process may have its widest application.

The sprinkler system uses solid set aluminum piping with 140 foot effective distribution diameter sprinkler heads placed in a rectangular spacing of 98 ft by 70 ft and with 3-foot risers.

Operation

Operation of the system assumes that the municipality must provide its own sprayfield which is capable of receiving the entire flow. While it is realized that this water can be of great benefit to private agricultural lands, it is felt that continuous, uninterrupted disposal on these private lands would not be possible. On this basis, sale of effluent to owners adjacent to the transmission pipeline would be a definite possibility. Calculations on the returns available from this sale under climatic conditions similar to those in central Pennsylvania indicated it would be an insignificant fraction of the total cost and it has not been included in these estimates.

Labor costs were estimated at $3.00 per hour for semi-skilled labor on a basis of manually operated irrigation changes involving one hour per 60 acres in the spring, summer and fall and two hours per 60 acres in the winter.

Power costs are computed as the cost required to deliver the effluent to the field distribution system at zero pressure after a distance of one mile and an elevation difference of 200 feet and the cost to operate the field distribution system at a 2-inch per week loading depth and a 1/6 inch per hour application rate.

Amortization costs were based on a 20-year period at 6% interest.

No detailed economic analysis was made of the profits which might accrue from operating the disposal area as a crop production area. An economic analysis of the Muskegon County project (112) indicated a potential net annual return to the operator for land, risk, management and labor ranging from $2.50 to $40.50 per acre from sale of baled hay and $25 to $75 per acre for lawn sod harvested every other year. Rental rates of the irrigated land to farmers could net from $5 to $20 per acre per year depending on the productivity of the site and value of the crops grown.

On the basis of the selected design parameters and ignoring any agricultural benefits, irrigation sales, recharge benefits or environmental benefits to the surface waters of a region, the estimated cost for flows of one, five, and ten MGD are shown in Table 165 in 1967 dollars. The percent distribution of the costs is also given in the table.

The data indicate that capital cost varies from $439,220 for a one mgd system to $2,431,280 for a ten mgd system. Annual cost also shown on Table 165 includes amortization of the capital cost in 20 years at 6%

Table 165. Costs of a Land Disposal System for Treated Municipal Wastewater (1967 dollars)

	Flow - MGD					
Item	1	%	5	%	10	%
Capital Costs						
Pumping system:						
Pump station, screens	84,000	19.1	179,000	13.1	258,500	10.6
Storage lagoon	123,000	28.0	350,000	25.6	600,000	24.7
Delivery system:						
Pipeline - 1 mile	71,500	16.3	132,000	9.6	195,000	8.0
Land, survey, site preparation	44,000	10.0	219,000	16.0	440,000	18.1
Distribution system	66,020	15.0	336,700	24.6	675,380	27.8
Engineering & Contingencies	50,700	11.6	152,100	11.1	262,400	10.8
Total Capital Cost	439,220	100.0	1,369,500	100.0	2,431,280	100.0
Annual Cost						
Amortization (20 yr., 6%)	36,750	78.9	111,100	75.7	197,800	75.2
Labor	1,900	4.1	1,900	1.3	1,900	0.7
Power - Transmission system - 1 mile + 200 ft elevation	2,310	5.0	11,740	8.0	21,260	8.1

Table 165. Continued.

Item	Flow - MGD					
	1	%	5	%	10	%
Power - Distribution system - irrigation	2,200	4.7	10,800	7.3	21,600	8.2
Maintenance and Contingencies	3,410	7.3	11,300	7.7	20,500	7.8
Total Annual Cost	46,570	100.0	146,840	100.0	263,060	100.0

interest and ranges from $46,570 to $263,060 for the one and ten mgd flows. Labor would be by personnel also used for other work and is considered constant in this flow range.

Although the distribution of costs among the various system components is given in Table 165, they are presented graphically in Figure 132. In this figure it can be seen that the capital costs are not equally distributed among the system components. The 40-day storage lagoon is the largest single cost component ranging from 28% to 24% of the total capital cost. Since the cost of the transmission pipeline would be almost directly proportional to length it is obvious that a large change in length of the pipeline could change the total figures considerably.

Annual wastewater treatment costs are often expressed in terms of cents per thousand gallons of wastewater treated. Annual cost on this basis is presented in Figure 133.

The cost shown in Figure 133 compares favorably with other wastewater treatment costs. With secondary treatment cost at 15 cents per thousand gallons for a 10 mgd plant, sprinkler irrigation would add 7.2¢ per thousand gallons or about 48 percent to the total treatment costs. Chemical treatment for phosphorus removal is generally estimated at about 5 cents per thousand gallons, and tertiary treatment by filtration and activated carbon at 20 cents. Nitrogen removal by denitrification would add about 5 cents per thousand gallons. The total cost for conventional physical-chemical treatment would thus total 30¢ as against 22.2¢ via the spray irrigation path.

Since the cost for wastewater treatment will always revert to the individual homeowner, Figure 134 was prepared to show the cost per equivalent dwelling unit (E.D.U.). The transformation from Figure 133 to Figure 134 is based on an average household of 3.5 people at 100 gallons per capita per day. The approximate cost per E.D.U. ranges from $13.00 per year for 1 MGD to $8.00 per year for 10 MGD.

If a net return from agricultural use of the disposal site were only $10 per acre the resultant annual income would decrease the annual operating cost by 2.8% in the 1 MGD system and 4.9% in the 10 MGD system.

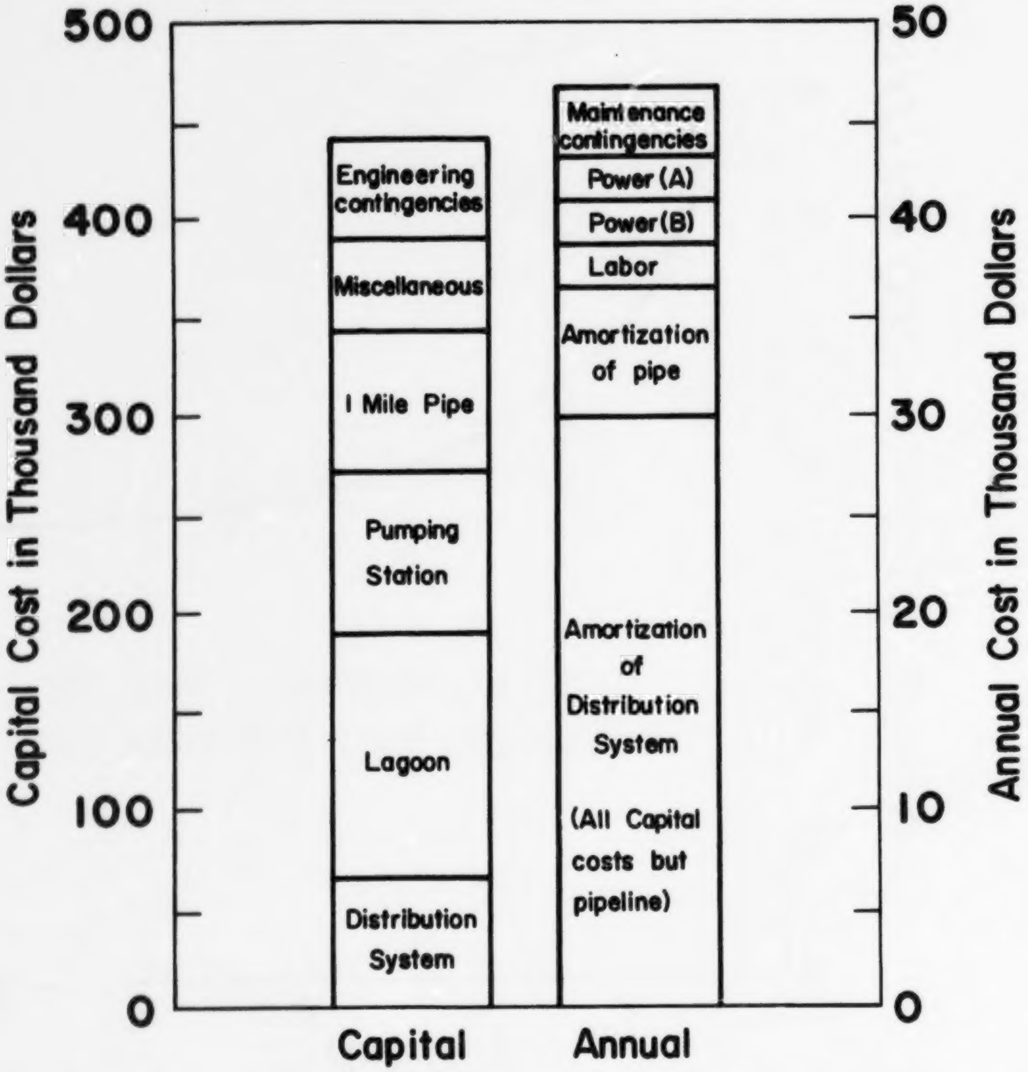

Figure 132. Capital and Annual Cost Distribution for a 1 MGD Spray Irrigation Wastewater Disposal System.

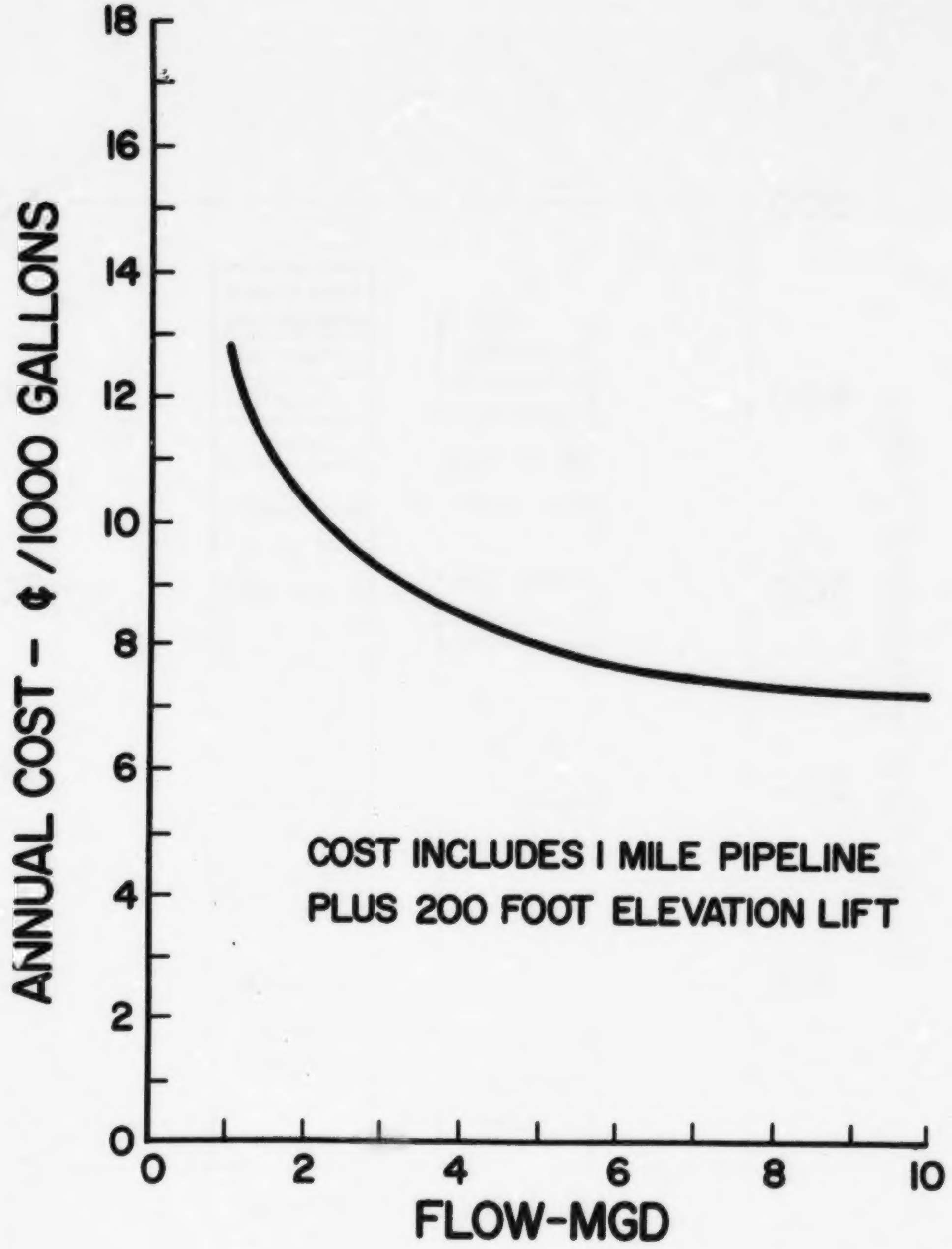

Figure 133. Annual Cost of Spray Irrigation Wastewater Disposal System per Thousand Gallons for Various Daily Flows.

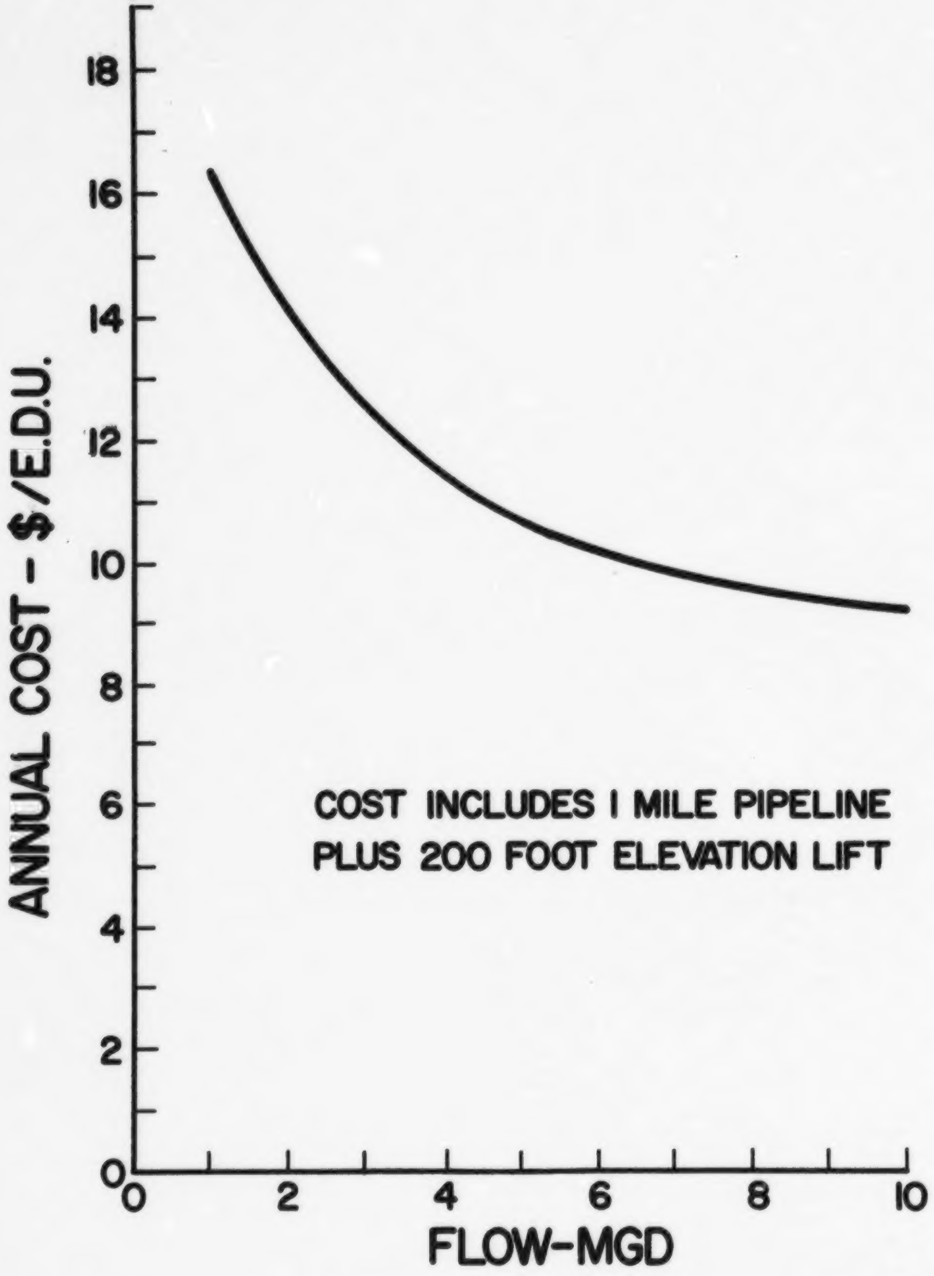

Figure 134. Annual Cost of Spray Irrigation Wastewater Disposal System per Equivalent Dwelling Unit (EDU) for Various Daily Flows.

SECTION X

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Accomplishments of the Waste Water Renovation and Conservation Research Project have resulted from the cooperation of many persons and agencies both in and out of the University. The initial phases of the work, 1962-1965, were financed by the Penn State Central Fund for Research and Agricultural Experiment Station Hatch and State Funds. Several members of the Pa. Dept. of Health assisted in the initial planning and preparation of an application for a Sanitary Water Board permit authorizing the study.

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In addition to the graduate students whose contributions are acknowledged in various citations the contribution of various former and present research assistants and technicians is also gratefully acknowledged, notably among these are: Joseph Eichert, Charles Robbins, Forrest Long and William Haas.

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SECTION XI

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SECTION XIII

APPENDICES

Page No.

A. Tables . . . .

A-1 Average Nutrient Composition (Percent) of Crop Receiving Various Levels of Sewage Effluent Per Week - 1963 436

A-2 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Crop Receiving Various Levels of Sewage Effluent Per Week - 1964 437

A-3 Average Nutrient Composition (Percent) of Crop Receiving Various Levels of Sewage Effluent Per Week - 1963 438

A-4 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Crops Receiving Various Levels of Sewage Effluent Per Week - 1965 439

A-5 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Crops Receiving Various Levels of Sewage Effluent Per Week - 1966 440

A-6 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Crop Receiving Various Levels of Sewage Effluent Per Week - 1967 441

A-7 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1965 442

A-8 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1966 443

A-9 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1967 444

A-10 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1968 445

A-11 Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1969 446

Preceding page blank

Page No.

A. Tables (Continued) . . . .

A-12 Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1963 447

A-13 Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1964 448

A-14 Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1963 449

A-15 Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1965 450

A-16 Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1966 451

A-17 Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1967 452

A-18 Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1965 453

A-19 Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1966 454

A-20 Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1967 455

A-21 Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1968 456

A-22 Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1969 457

Page No.

A. Tables (Continued) . . . .

A-23 Chemical Composition of the Sewage Effluent and Amounts of Constituents Applied on the 2-inches Per Week Plots During 1965 458

A-24 Average Concentration of Constituents in the Combined Effluent and Storm Percolate Samples from Tension Lysimeters of the Original Forestry Plots (Farm Woodlot Site) During the Irrigation Period 4/20/65 to 11/16/65 459

A-25 Average Concentration of Constituents in the Percolate Samples of the Original Forestry Control Plots (Farm Woodlot Site) During the Period 4/20/65 to 11/16/65 460

A-26 Chemical Composition of Sewage Effluent Applied on Original Forestry Experimental Plots (Farm Woodlot Site) During the Period 4/5/66 to 11/16/66 461

A-27 Average Concentration of Constituents in the Combined Effluent and Storm Percolate Samples of the Original Forestry Plots (Farm Woodlot Site) During the Irrigation Period 4/5/66 to 11/15/66 462

A-28 Average Concentration of Constituents in the Percolate Samples of the Original Forestry Control Plots (Farm Woodlot Site) During the Period 4/2/66 to 11/15/66 463

A-29 Chemical Composition of Sewage Effluent Applied on Original Forestry Experimental Plots (Farm Woodlot Site) During the Period 4/18/67 to 10/31/67 464

A-30 Average Concentration of Constituents in the Combined Effluent and Storm Percolate Samples of the Original Forestry Plots (Farm Woodlot Site) During the Irrigation Period 4/18/67 to 10/31/67 465

A-31 Average Concentration of Constituents in the Percolate Samples of the Original Forestry Control Plots (Farm Woodlot Site) During the Period 4/18/67 to 10/31/67 466

A-32 Chemical Composition of Sewage Effluent Applied on Original Forestry Experimental Plots (Farm Woodlot Site) During the Period 4/9/68 to 11/12/68 467

Page No.

A. Tables (Continued) . . . .

A-33 Average Concentration in Percolate Samples and in the Sewage Effluent for the Original Forestry Plots (Farm Woodlot Site) During the Irrigation Period: 4/9/68 to 11/12/68 468

A-34 Average Concentration of Constituents in the Percolate Samples of the Original Forestry Control Plots (Farm Woodlot Site) During the Period 4/9/68 to 11/12/68 470

A-35 Average Concentration of Percolate Samples and of Sewage Effluent in the New Red Pine - 2 inches Per Week Area. 1965 and 1966 471

A-36 Average Concentration in Percolate Samples and in Sewage Effluent for the New Red Pine - 2 inches Per Week Area. 1967 and 1968 472

A-37 Average Concentration of Percolate Samples and of Sewage Effluent in the New Gamelands Area. 1966 and 1967 473

A-38 Average Concentration of Percolate in the Hardwood Control Plot at the New Gamelands Site. 1966 and 1967 474

A-39 Average Concentration in Percolate Samples and Sewage Effluent for the Hardwoods New Gamelands Area which Received 2 Inches of Effluent Per Week During the Period 1/1/68 to 12/31/68 and for a Nearby Control Area 475

A-40 Average Concentration of Constituents in the Percolate at Various Soil Depths on the Plot which Received 4 Inches Per Week During 1965 476

A-41 Average Concentration of Constituents in the Percolate Samples Collected from Pan Lysimeters Located in the Hardwood Plot which Received 4 Inches of Effluent Per Week During the Period 4/5/66 to 11/17/66 477

A-42 Average Concentration of Constituents in the Percolate Samples Collected from Pan Lysimeters Located in the Hardwood Plot which Received 4 Inches of Effluent Per Week During the Period 4/18/67 to 10/31/67 478

Page No.

A. Tables (Continued) . . . .

A-43 Mean Nutrient Element Concentration of the Soil Samples Collected in 1963, 1964, and 1965 in the Red Pine 1-inch Treatment and Control Plots 479

A-44 Mean Chemical Element Concentration of the Soil Samples Collected in 1963, 1964, and 1965 in the Red Pine 2-inch Treatment and Control Plots 481

A-45 Mean Nutrient Element Concentration of the Soil Samples Collected in 1963, 1964, 1965 in the Open Area 2-inch Treatment and Control Plots 483

Table A-1. Average Nutrient Composition (Percent) of Crop Receiving Various Levels of Sewage Effluent Per Week - 1963

	Crop and Inches of Effluent Applied Per Week								
	RED CLOVER								
	1st Cut			2nd Cut			Weighted Averages		
Nutrient	0	1	2	0	1	2	0	1	2
Nitrogen	1.74	2.28	2.46	2.09	2.13	2.15	1.86	2.21	2.29
Phosphorus	0.185	0.262	0.234	0.276	0.271	0.293	0.217	0.266	0.266
Potassium	1.99	2.73	2.69	2.25	2.65	2.62	2.08	2.69	2.65
Calcium	0.913	1.428	1.402	1.334	1.135	1.208	1.060	1.296	0.298
Magnesium	0.134	0.217	0.214	0.214	0.240	0.255	0.162	0.227	0.236

Table A-2. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Crop Receiving Various Levels of Sewage Effluent Per Week - 1964

	Crop and Inches of Effluent Applied Per Week								
	RED CLOVER								
	1st Cut			2nd Cut			Weighted Averages		
Nutrient	0	1	2	0	1	2	0	1	2
					Percent				
Nitrogen	1.97	2.44	1.93	2.35	3.22	3.13	2.03	2.72	2.38
Phosphorus	0.187	0.300	0.264	0.214	0.371	0.345	0.191	0.326	0.294
Potassium	1.90	3.05	2.69	1.89	3.09	2.98	1.90	3.06	2.79
Calcium	0.621	0.900	0.606	0.938	1.034	0.715	0.672	0.948	0.653
Magnesium	0.129	0.295	0.211	0.197	0.350	0.270	0.140	0.315	0.233
Chloride	0.41	1.06	1.28	0.36	1.07	1.21	0.40	1.06	1.25
					Micrograms Per Grams				
Boron	14	24	13	22	29	18	15	26	15

Table A-3. Average Nutrient Composition (Percent) of Crop Receiving Various Levels of Sewage Effluent Per Week - 1963

	Crop and Inches of Effluent Applied Per Week								
	ALFALFA								
	1st Cut			2nd Cut			Weighted Averages		
Nutrient	0	1	2	0	1	2	0	1	2
Nitrogen	1.40	1.89	1.72	2.49	1.95	2.05	1.75	1.92	1.87
Phosphorus	0.224	0.244	0.271	0.292	0.375	0.362	0.245	0.308	0.313
Potassium	1.91	2.12	2.09	2.04	2.39	2.51	1.95	2.25	2.28
Calcium	0.530	0.823	0.463	0.891	0.513	0.417	0.646	0.670	0.442
Magnesium	0.109	0.145	0.121	0.150	0.160	0.165	0.122	0.152	0.141

Table A-4. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Crops Receiving Various Levels of Sewage Effluent Per Week - 1965

	Crop and Inches of Effluent Applied Per Week											
	ALFALFA											
	1st Cut			2nd Cut			3rd Cut			Weighted Averages		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
	Percent											
Nitrogen	1.68	2.30	2.06	3.20	3.36	3.33	3.26	2.98	3.21	2.12	2.66	2.62
Phosphorus	0.174	0.248	0.279	0.201	0.324	0.317	0.217	0.391	0.386	0.185	0.293	0.312
Potassium	2.00	2.39	2.72	1.40	2.36	2.43	2.18	3.11	3.22	2.04	2.55	2.75
Calcium	0.849	0.647	0.665	0.919	0.642	0.689	1.353	0.649	0.612	0.980	0.647	0.660
Magnesium	0.116	0.215	0.241	0.140	0.211	0.199	0.176	0.224	0.215	0.132	0.216	0.225
Chloride	0.47	0.95	1.12	0.37	1.17	1.14	0.71	1.68	1.63	0.53	1.16	1.23
	Micrograms Per Gram											
Boron	14	18	22	9	11	13	16	17	17	14	16	19

Table A-5. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Crops Receiving Various Levels of Sewage Effluent Per Week - 1966

	Crop and Inches of Effluent Applied Per Week											
	ALFALFA											
	1st Cut			2nd Cut			3rd Cut			Weighted Averages		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
	Percent											
Nitrogen	1.90	1.42	1.25	2.30	1.99	1.92	3.67	2.89	2.58	2.91	2.35	2.14
Phosphorus	0.246	0.311	0.340	0.260	0.337	0.282	0.293	0.380	0.377	0.244	0.327	0.330
Potassium	1.05	1.07	1.16	2.36	2.59	2.50	1.81	2.38	2.59	2.48	2.83	2.78
Calcium	0.42	0.31	0.28	0.79	0.68	0.52	1.06	0.66	0.56	1.03	0.66	0.54
Magnesium	0.18	0.20	0.20	0.18	0.22	0.20	0.14	0.22	0.21	0.15	0.20	0.19
Chloride	0.33	0.40	0.39	0.83	1.22	1.33	0.63	1.31	1.39	0.55	1.07	1.22
	Micrograms Per Gram											
Sodium	13	250	211	25	327	248	24	272	272	23	224	197
Boron	5	5	5	12	14	11	18	12	10	17	14	10

Table A-6. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Crop Receiving Various Levels of Sewage Effluent Per Week - 1967

	Crop and Inches of Effluent Applied Per Week								
	ALFALFA								
	1st Cut			2nd Cut			Weighted Averages		
Nutrient	0	1	2	0	1	2	0	1	2
					Percent				
Nitrogen	1.32	1.28	1.46	2.46	2.36	3.52	1.82	1.54	2.10
Phosphorus	0.21	0.24	0.25	0.32	0.42	0.40	0.26	0.28	0.30
Potassium	2.05	2.29	2.42	2.42	2.72	2.76	2.21	2.39	2.53
Calcium	0.54	0.39	0.36	1.46	0.55	0.46	0.95	0.43	0.39
Magnesium	0.11	0.13	0.14	0.20	0.19	0.19	0.15	0.14	0.16
Chloride	0.62	0.91	1.12	0.61	1.48	1.33	0.62	1.04	1.18
					Micrograms Per Gram				
Sodium	26	154	121	38	155	235	31	154	157
Boron	10	8	7	26	12	10	17	9	8

Table A-7. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1965

Nutrient	1st Cut	2nd Cut	3rd Cut	Weighted Averages
		Percent		
Nitrogen	2.44	3.29	3.46	3.00
Phosphorus	0.32	0.27	0.47	0.33
Potassium	2.58	2.35	3.11	2.63
Calcium	0.44	0.64	0.51	0.54
Magnesium	0.24	0.22	0.33	0.25
Chloride	1.38	1.52	1.95	1.56
		Micrograms Per Gram		
Sodium	482	267	488	408
Boron	9	8	8	8

Table A-8. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1966

Nutrient	1st Cut	2nd Cut	3rd Cut	Weighted Averages
		Percent		
Nitrogen	3.18	3.18	2.85	3.15
Phosphorus	0.36	0.44	0.40	0.39
Potassium	3.06	2.90	1.80	2.90
Calcium	0.34	0.31	0.37	0.33
Magnesium	0.20	0.26	0.20	0.22
Chloride	1.39	1.54	1.11	1.41
		Micrograms Per Gram		
Sodium	117	151	224	137
Boron	7	3	6	6

Table A-9. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1967

Nutrient	1st Cut	2nd Cut	3rd Cut	Weighted Averages
		Percent		
Nitrogen	2.21	2.59	2.35	2.34
Phosphorus	0.36	0.42	0.47	0.40
Potassium	2.58	2.62	1.80	2.44
Calcium	0.44	0.41	0.58	0.46
Magnesium	0.27	0.28	0.35	0.29
Chloride	1.34	1.60	1.50	1.44
		Micrograms Per Gram		
Sodium	332	259	441	334
Boron	7	8	6	7

Table A-10. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1968

Nutrient	1st Cut	2nd Cut	Weighted Averages
	Percent		
Nitrogen	4.09	2.65	3.50
Phosphorus	0.46	0.47	0.46
Potassium	3.00	1.79	2.50
Calcium	0.47	0.30	0.40
Magnesium	0.27	0.28	0.28
Chloride	0.27	0.28	0.28
	Micrograms Per Gram		
Sodium	360	224	304
Boron	5	5	5

Table A-11. Average Nutrient Composition (in Percent or Micrograms Per Gram) of Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1969

Nutrient	1st Cut	2nd Cut	3rd Cut	Weighted Averages
		Percent		
Nitrogen	3.54	3.36	3.06	3.42
Phosphorus	0.39	0.52	0.57	0.45
Potassium	2.23	1.86	1.92	2.07
Calcium	0.47	0.46	0.50	0.47
Magnesium	0.39	0.29	0.33	0.35
Chloride	2.09	1.14	1.27	1.67
		Micrograms Per Gram		
Sodium	325	124	328	259
Boron	11	9	12	11

Table A-12. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1963

Nutrient	Crop and Inches of Effluent Applied Per Week RED CLOVER 1st Cut			2nd Cut			Total Quantities		
	0	1	2	0	1	2	0	1	2
Nitrogen	56.0	123.1	105.3	36.4	93.7	105.4	91.4	216.8	210.7
Phosphorus	6.0	14.1	10.0	4.8	11.9	14.4	10.8	26.0	24.4
Potassium	64.2	147.3	115.0	39.2	116.8	128.5	103.4	264.1	243.5
Calcium	29.4	77.1	60.0	23.2	49.9	59.2	52.6	127.0	119.2
Magnesium	4.3	11.7	9.2	3.7	10.6	12.5	8.0	22.3	21.7

Table A-13. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1964

Nutrient	Crop and Inches of Effluent Applied Per Week								
	RED CLOVER								
	1st Cut			2nd Cut			Total Quantities		
	0	1	2	0	1	2	0	1	2
Nitrogen	58.3	164.9	124.3	13.2	123.6	118.9	71.5	288.5	243.2
Phosphorus	5.6	20.3	16.7	1.2	14.2	12.9	6.8	34.5	29.6
Potassium	56.2	206.2	173.2	10.6	118.6	113.2	66.8	324.8	286.4
Calcium	18.4	60.8	39.3	5.3	39.6	27.4	23.7	100.4	66.7
Magnesium	3.8	20.3	13.5	1.1	13.4	10.3	4.9	33.7	23.8
Chloride	12.1	71.6	82.4	2.0	41.1	46.0	14.1	112.7	128.4
Boron	0.04	0.17	0.08	0.01	0.11	0.07	0.05	0.28	0.15

Table A-14. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1963

	Crop and Inches of Effluent Applied Per Week								
	ALFALFA								
	1st Cut			2nd Cut			Total Quantities		
Nutrient	0	1	2	0	1	2	0	1	2
Nitrogen	41.4	71.4	94.9	34.9	71.8	96.8	76.1	143.2	191.7
Phosphorus	6.6	9.2	15.0	4.1	13.8	17.0	10.7	23.0	32.0
Potassium	56.4	79.9	115.5	28.6	88.0	118.5	85.0	167.9	234.0
Calcium	15.7	31.1	25.6	12.5	18.9	19.7	28.2	50.0	45.3
Magnesium	3.2	5.5	6.7	2.1	5.9	7.8	5.3	11.4	14.5

Table A-15. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1965

	Crop and Inches of Effluent Applied Per Week											
	ALFALFA											
	1st Cut			2nd Cut			3rd Cut			Total Quantities		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
Nitrogen	54.8	125.1	120.7	3.2	59.8	91.9	38.5	63.2	71.3	96.5	248.1	283.9
Phosphorus	5.7	13.5	16.3	0.2	5.8	8.7	2.6	8.3	8.6	8.5	27.6	33.6
Potassium	65.2	130.0	159.4	1.4	42.0	67.1	25.7	65.9	71.5	92.3	237.9	298.0
Calcium	27.7	35.2	39.0	0.9	11.4	19.0	16.0	13.8	13.6	44.6	60.5	71.6
Magnesium	3.8	11.7	14.1	0.1	3.8	5.5	2.1	4.7	4.8	6.0	20.2	24.4
Chloride	15.3	51.7	65.6	0.4	20.8	31.5	8.4	35.6	36.2	24.1	108.1	133.3
Boron	0.04	0.10	0.13	0.01	0.02	0.04	0.02	0.04	0.04	0.07	0.16	0.21

Table A-16. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1966

	Crop and Inches of Effluent Applied Per Week											
	ALFALFA											
	1st Cut			2nd Cut			3rd Cut			Total Quantities		
Nutrient	0	1	2	0	1	2	0	1	2	0	1	2
Nitrogen	86.7	103.3	90.1	14.5	43.5	57.5	11.2	32.8	37.2	112.4	179.6	184.8
Phosphorus	7.0	13.4	14.7	1.8	7.4	8.4	0.9	4.2	5.5	9.7	25.0	28.6
Potassium	74.6	133.0	127.5	16.0	59.3	76.5	5.2	27.2	38.1	95.8	219.5	242.1
Calcium	30.0	28.5	22.8	5.0	16.1	15.8	2.7	7.3	8.0	37.7	51.9	46.6
Magnesium	4.2	7.7	7.1	1.1	4.9	6.1	0.4	2.5	3.0	5.7	15.1	16.2
Chloride	86.7	103.3	90.1	14.5	43.5	57.5	11.2	32.8	37.2	21.4	83.0	105.5
Sodium	0.07	0.67	0.71	0.04	0.83	0.76	0.01	0.31	0.39	0.12	1.81	1.86
Boron	0.03	0.06	0.04	0.01	0.03	0.03	0.01	0.01	0.01	0.07	0.10	0.08

Table A-17. Quantities of Nutrients (Pounds Per Acre) Removed by Crops Receiving Various Levels of Sewage Effluent Per Week - 1967

	Crop and Inches of Effluent Applied Per Week								
	ALFALFA								
	1st Cut			2nd Cut			Total Quantities		
Nutrient	0	1	2	0	1	2	0	1	2
Nitrogen	37.9	72.9	75.6	32.1	42.0	57.3	70.0	114.9	132.9
Phosphorus	5.6	13.8	14.9	3.0	7.5	9.4	8.6	21.3	24.3
Potassium	52.8	132.5	143.2	21.8	48.6	65.8	74.6	181.1	209.0
Calcium	12.9	22.2	21.6	12.9	9.6	10.4	25.8	31.8	32.0
Magnesium	2.7	7.6	8.0	1.9	3.4	4.3	4.6	11.0	12.4
Chloride	14.8	51.1	65.2	5.6	26.4	29.6	20.4	77.5	94.8
Sodium	0.06	0.88	0.72	0.03	0.28	0.55	0.09	1.16	1.27
Boron	0.02	0.05	0.04	0.02	0.02	0.04	0.04	0.07	0.08

Table A-18. Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1965

Nutrient	1st Cut	2nd Cut	3rd Cut	Total
Nitrogen	131.8	155.2	66.1	353.1
Phosphorus	17.9	13.1	9.0	40.0
Potassium	142.7	119.4	59.8	321.9
Calcium	23.7	28.4	9.9	62.0
Magnesium	13.2	10.3	6.3	29.8
Chloride	77.2	73.0	37.4	187.6
Sodium	2.54	1.30	0.92	4.76
Boron	0.05	0.03	0.02	0.10

Table A-19. Quantities of Nutrients (Pound Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1966

Nutrient	1st Cut	2nd Cut	3rd Cut	Total
Nitrogen	163.4	87.1	21.7	272.2
Phosphorus	18.4	12.0	3.0	33.4
Potassium	157.3	79.5	13.7	250.5
Calcium	17.5	8.5	2.8	28.8
Magnesium	10.3	7.1	1.5	18.9
Chloride	71.4	42.2	8.4	122.0
Sodium	0.60	0.41	0.17	1.18
Boron	0.03	0.01	0.01	0.05

Table A-20. Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1967

Nutrient	1st Cut	2nd Cut	3rd Cut	Total
Nitrogen	166.6	97.4	64.9	328.9
Phosphorus	27.1	15.8	13.0	55.9
Potassium	194.5	98.5	49.7	342.7
Calcium	33.2	15.4	16.0	64.6
Magnesium	20.4	10.5	9.7	40.6
Chloride	101.0	60.2	41.4	202.6
Sodium	2.50	0.97	1.22	4.69
Boron	0.05	0.03	0.02	0.10

Table A-21. Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1968

Nutrient	1st Cut	2nd Cut	Total
Nitrogen	254.4	110.8	356.2
Phosphorus	27.6	19.6	47.2
Potassium	180.0	74.8	254.8
Calcium	28.2	12.5	40.7
Magnesium	16.2	11.7	27.9
Chloride	118.2	51.4	169.6
Sodium	2.16	0.93	3.09
Boron	0.03	0.02	0.05

Table A-22. Quantities of Nutrients (Pounds Per Acre) Removed by Reed Canarygrass Receiving Two Inches of Sewage Effluent Per Week - 1969

Nutrient	1st Cut	2nd Cut	3rd Cut	Total
Nitrogen	200.4	114.9	39.2	354.5
Phosphorus	22.1	17.8	7.3	47.2
Potassium	126.2	63.6	24.6	214.4
Calcium	26.6	15.7	6.4	48.7
Magnesium	22.1	9.9	4.2	36.2
Chloride	118.3	39.0	16.2	173.5
Sodium	1.84	0.42	0.42	2.68
Boron	0.06	0.03	0.02	0.11

Table A-23. Chemical Composition of the Sewage Effluent and Amounts of Constituents Applied on the 2-inches Per Week Plots During 1965

Constituent	Range Min	Range Max	Ave	Total amount applied
	mg/1	mg/1	mg/1	lb/acre
pH	7.0	8.2	7.5	
MBAS	0.4	2.5	1.6	22
Nitrate-N	3.0	13.1	7.6	103
Organic-N[1/]	0.0	6.5	2.7	36
Phosphorus	3.812	13.232	10.383	122
Potassium	7.2	24.3	16.3	199
Calcium	12.8	48.8	29.5	360
Magnesium	5.9	23.8	14.8	181
Sodium	0.0	54.2	33.7	459
Chloride	22.1	63.2	46.2	545
Boron	0.0	0.6	0.3	4

[1/] Includes ammoniacal nitrogen

Table A-24. Average Concentration of Constituents in the Combined Effluent and Storm Percolate Samples from Tension Lysimeters of the Original Forestry Plots (Farm Woodlot Site) During the Irrigation Period 4/20/65 to 11/16/65.

	pH	ABS	NO_3-N	Org-N	P	K	Ca	Mg	Na	Cl
				Concentration in mg/1						
Effluent Quality	7.5	1.61	7.6	2.7	10.383	16.3	29.5	14.8	33.7	46.2
Hardwood 1"										
Forest Floor Pans	6.7	0.19	13.5	3.5	5.061	16.8	22.0	8.6	20.7	28.0
6" Tension Lysimeter	7.6	0.07	1.0	2.1	.234	2/	2/	2/	2/	49.5
24" Tension Lysimeter	7.2	0.02	0.2	3.0	.390	9.8	21.1	11.6	35.2	84.7
48" Tension Lysimeter	7.2	0.01	0.0	2/	.250	6.3	12.2	11.2	8.3	20.3
Red Pine 1"										
Forest Floor Pans	6.7	0.27	10.8	4.7	12.841	16.4	30.6	8.4	23.3	36.5
6" Tension Lysimeter	7.1	0.06	1.7	2/	.178	2/	2/	2/	2/	58.0
24" Tension Lysimeter	6.8	0.03	0.04	1.5	.190	6.3	9.1	3.8	20.9	49.1
48" Tension Lysimeter	7.0	0.03	2.2	1.3	.300	7.2	8.5	4.5	8.5	14.3
Red Pine 2"										
Forest Floor Pans	7.0	0.55	14.6	3.1	6.858	17.9	26.5	14.4	32.1	43.9
6" Tension Lysimeter	7.3	0.11	9.2	2/	0.335	7.9	12.7	6.6	39.2	98.3
24" Tension Lysimeter	6.9	0.04	10.7	0.8	.517	7.2	13.3	5.1	40.1	91.2
48" Tension Lysimeter	6.7	0.05	3.9	1.4	.400	5.8	4.8	1.7	22.5	38.9
Old Field 2"										
6" Tension Lysimeter	7.2	0.08	5.1	2/	.402	7.9	14.8	3.7	33.4	45.5
24" Tension Lysimeter	7.1	0.12	8.4	0.7	.116	8.7	13.0	3.4	33.4	44.5
48" Tension Lysimeter	6.5	0.06	8.0	0.8	.460	8.7	3.8	3.4	29.1	44.8

2/ Insufficient sample volume for complete chemical analyses

Table A-25. Average Concentration of Constituents in the Percolate Samples of the Original Forestry Control Plots (Farm Woodlot Site) During the Period 4/20/65 to 11/16/65

	pH	ABS	NO_3-N	Org-N1/	P	K	Ca	Mg	Na	Cl
				Concentration in ppm						
Hardwood 1" Control										
6" Tension Lysimeter	7.2	0.09	0.1	*	.065	*	*	*	*	4.8
24" Tension Lysimeter	8.0	*	*	*	.010	*	*	*	*	3.5
48" Tension Lysimeter	7.4	0.01	30.3	*	.050	*	*	*	*	8.9
Red Pine 1" Control										
6" Tension Lysimeter	7.9	*	0.3	*	*	*	*	*	*	7.5
24" Tension Lysimeter	*	*	*	*	*	*	*	*	*	*
48" Tension Lysimeter	*	*	*	*	*	*	*	*	*	*
Red Pine 2" Control										
6" Tension Lysimeter	7.4	*	0.1	*	.450	*	*	*	*	14.2
24" Tension Lysimeter	*	*	*	*	*	*	*	*	*	*
48" Tension Lysimeter	6.9	*	0.9	*	.040	*	*	*	*	3.4
Old Field 2" Control										
6" Tension Lysimeter	6.9	0.02	0.1	*	.065	*	*	*	*	2.6
24" Tension Lysimeter	6.8	0.02	0.0	0.5	.385	10.4	10.8	3.3	2.6	0.9
48" Tension Lysimeter	6.8	0.05	0.3	1.6	.395	5.6	2.8	1.0	1.4	0.8

1/ Includes ammoniacal nitrogen

* Insufficient Sample

Table A-26. Chemical Composition of Sewage Effluent Applied on Original Forestry Experimental Plots (Farm Woodlot Site) During the Period 4/5/66 to 11/15/66.

Constituent	Range Min	 Max	Average
	mg/1	mg/1	mg/1
pH	7.1	8.2	7.6
MBAS	0.1	1.5	0.4
Nitrate-N	1.9	20.3	7.5
Organic-N[1/]	2.0	12.2	5.0
Phosphorus	4.331	17.161	9.520
Potassium	5.7	31.8	17.5
Calcium	8.9	44.4	28.5
Magnesium	4.3	31.9	17.3
Sodium	14.3	49.1	33.4
Chloride	17.5	87.4	46.3
Boron	0.12	0.80	0.36
Manganese	0.01	0.18	0.05

[1/] Includes ammoniacal nitrogen

Tabel A-27. Average Concentration of Constituents in the Combined Effluent and Storm Percolate Samples of the Original Forestry Plots (Farm Woodlot Site) Druing the Irrigation Period 4/5/66 to 11/15/66.

	pH	MBAS	NO_3-N	Org-N2/	P	K	Ca	Mg	Na	Cl	Mn	B
				Concentration in mg/liter								
Effluent Quality	7.6	0.40	7.5	5.0	9.520	17.5	28.5	17.3	33.4	46.3	0.05	0.36
Hardwood 1-inch												
Forest Floor Pans	6.9	0.16	13.0	3.9	5.094	17.3	22.3	9.2	22.6	28.7	0.17	0.20
6" Tension Lysimeter	7.5	0.07	3.3	1/	0.429	10.7	14.9	10.5	46.3	37.1	0.07	0.18
24" Tension Lysimeter	7.1	0.04	2.1	2.0	0.077	6.6	11.8	8.0	32.6	64.9	0.03	0.07
48" Tension Lysimeter	7.2	0.02	0.2	1.2	0.043	5.6	6.9	7.0	17.6	40.5	0.07	0.04
Red Pine 1-inch												
Forest Floor Pans	6.8	0.14	13.4	4.7	4.965	15.8	23.2	9.8	24.2	32.2	0.04	0.18
6" Tension Lysimeter	7.0	1/	1.5	1/	0.202	1/	1/	1/	1/	46.0	1/	1/
24" Tension Lysimeter	6.7	0.04	0.2	0.8	0.024	6.9	7.9	2.6	27.7	48.4	0.08	0.04
48" Tension Lysimeter	7.2	0.09	2.1	0.9	0.134	9.5	13.9	6.3	12.8	15.1	0.20	0.12
Red Pine 2-inch												
Forest Floor Pans	7.2	0.21	15.5	4.1	7.996	18.4	28.9	16.7	33.8	44.9	0.06	0.28
6" Tension Lysimeter	7.4	1/	26.8	1/	0.373	1/	1/	1/	1/	88.1	1/	1/
24" Tension Lysimeter	7.0	0.07	14.6	0.7	0.049	6.7	12.2	4.6	48.5	103.5	0.07	0.06
48" Tension Lysimeter	6.8	0.03	9.3	1.3	0.143	5.8	6.1	2.6	35.6	65.0	0.16	0.06
Old Field 2-inch												
6" Tension Lysimeter	7.1	0.08	4.3	1/	0.091	1/	1/	1/	1/	43.4	1/	1/
24" Tension Lysimeter	7.0	0.05	7.5	1.4	0.069	5.6	8.6	3.7	29.6	45.4	0.03	0.12
48" Tension Lysimeter	6.6	0.05	5.0	1.4	0.140	6.4	2.2	2.1	31.1	49.4	0.07	0.10

1/ Insufficient sample volume for complete chemical analyses

2/ Includes ammoniacal nitrogen

Table A-28. Average Concentration of Constituents in the Percolate Samples of the Original Forestry Control Plots (Farm Woodlot Site) During the Period 4/2/66 to 11/15/66.

	pH	MBAS	NO_3-N	Org-N[1/]	P	K	Ca	Mg	Na	Cl	Mn	B
	Concentration in mg/liter											
Hardwood 1" Control												
Forest Floor Pans	6.3	0.09	7.1	4.0	.569	11.5	17.0	1.7	1.2	1.6	0.16	0.08
6" Tension Lysimeter	7.1	0.04	0.1	2.4	.048	11.4	14.0	3.4	3.4	4.1	0.08	0.12
24" Tension Lysimeter	7.3	0.03	0.1	1.3	.034	7.6	19.2	16.9	2.4	1.6	0.05	0.05
48" Tension Lysimeter	6.7	0.03	0.1	1.3	.037	5.0	6.7	6.3	6.0	2.0	0.07	0.04
Red Pine Control Plots												
Forest Floor Pans	6.4	0.11	6.9	4.4	.394	9.0	18.1	1.7	1.5	1.7	0.10	0.06
1" Control												
6" Tension Lysimeter	6.9	0.00	0.1	*	.158	*	*	*	*	1.7	*	*
24" Tension Lysimeter	6.9	0.01	0.0	5.1	.053	2.4	7.0	2.5	3.5	2.6	0.12	0.06
48" Tension Lysimeter	6.8	0.01	0.0	0.7	.062	5.7	2.2	1.1	1.4	2.4	0.03	0.04
2" Control												
6" Tension Lysimeter	7.0	0.05	0.1	*	.156	*	*	*	*	1.6	*	*
24" Tension Lysimeter	6.7	0.03	0.3	1.7	.074	3.3	11.4	3.1	3.3	10.4	0.28	0.02
48" Tension Lysimeter	6.5	0.02	0.2	0.6	.022	3.9	2.5	0.8	3.0	5.2	0.05	0.03
Old Field 2" Control												
6" Tension Lysimeter	6.9	0.03	0.1	*	.038	16.2	15.8	2.8	2.8	1.3	0.04	0.02
24" Tension Lysimeter	6.9	0.08	0.4	*	.030	*	*	*	*	2.1	*	*
48" Tension Lysimeter	6.7	0.03	0.1	0.9	.030	10.0	3.5	1.1	8.4	0.5	0.05	0.06

* Insufficient sample for complete analyses

[1/] Includes ammoniacal nitrogen

Table A-29. Chemical Composition of Sewage Effluent Applied on Original Forestry Experimental Plots (Farm Woodlot Site) During the Period 4/18/67 to 10/31/67.

Constituent	Range Min	Range Max	Average
	mg/l	mg/l	mg/l
pH	6.9	8.1	7.0
MBAS	0.1	2.0	0.4
Nitrate-N	2.2	15.2	6.3
Organic-N[1]	0.0	8.2	4.5
Phosphorus	0.361	12.524	7.682
Potassium	3.5	28.6	13.9
Calcium	9.9	34.2	20.3
Magnesium	4.1	18.5	10.6
Sodium	15.8	51.3	35.4
Chloride	18.6	82.9	46.8
Boron	0.12	0.55	0.34
Manganese	0.00	0.62	0.06

[1] Includes ammoniacal nitrogen.

Table A-30. Average Concentration of Constituents in the Combined Effluent and Storm Percolate Samples of the Original Forestry Plots (Farm Woodlot Site) During the Irrigation Period 4/18/67 to 10/31/67.

	pH	MBAS	NO_3-N	Org-N[1/]	Cl	P	Na	K	Ca	Mg	Mn	B
					Concentration in mg/liter							
Effluent Quality	7.0	0.45	6.3	4.5	46.8	7.682	35.4	13.9	20.3	10.6	0.06	0.34
Hardwood 1-inch												
Forest Floor Pan	7.0	0.18	10.9	3.2	22.1	4.651	18.2	13.8	18.9	7.4	0.16	0.19
6" Tension Lysimeter	7.5	0.12	13.3	1.7	14.1	0.068	35.2	7.8	33.2	28.4	0.07	0.31
24" Tension Lysimeter	7.1	0.10	5.4	0.8	45.4	0.078	40.9	5.9	6.7	5.0	0.10	0.16
48" Tension Lysimeter	7.0	0.13	1.4	0.9	64.8	0.077	25.6	5.9	4.9	5.1	0.06	0.04
Red Pine 1-inch												
Forest Floor Pan	6.8	0.16	11.3	3.4	21.3	3.851	18.3	12.4	18.7	29.1	0.05	0.16
6" Tension Lysimeter	7.6	0.11	6.9	2.0	26.7	0.149	22.2	12.1	30.6	26.2	0.04	0.22
24" Tension Lysimeter	7.1	0.09	5.1	2.9	43.3	0.108	27.7	9.4	27.0	14.9	0.05	0.13
48" Tension Lysimeter	7.5	0.05	1.7	2.3	35.8	0.092	17.2	7.6	29.7	17.8	0.10	0.12
Red Pine 2-inch												
Forest Floor Pan	7.0	0.18	14.7	3.4	40.0	6.987	26.1	12.9	23.8	11.2	0.12	0.26
6" Tension Lysimeter	7.2	0.10	9.6	2.0	70.3	0.242	41.0	18.7	24.3	22.2	1.59	0.40
24" Tension Lysimeter	6.9	0.08	10.6	1.0	78.1	0.072	54.5	5.7	5.6	3.0	0.04	0.08
48" Tension Lysimeter	6.5	0.08	13.8	1.1	87.8	0.031	45.5	4.9	1.8	1.7	0.09	0.04
Old Field 2-inch												
6" Tension Lysimeter	7.6	0.09	4.6	2.8	33.9	0.136	32.4	9.2	27.1	15.4	0.10	0.33
24" Tension Lysimeter	7.4	0.05	12.0	1.1	33.7	0.097	42.4	7.7	20.1	14.0	0.03	0.21
48" Tension Lysimeter	6.8	0.06	6.1	0.8	42.5	0.068	34.7	6.0	1.1	1.1	0.03	0.17

[1/] Includes ammoniacal nitrogen

Table A-31. Average Concentration of Constituents in the Percolate Samples of the Original Forestry Control Plots (Farm Woodlot Site) During the Period 4/18/67 to 10/31/67.

	pH	MBAS	NO_3-N	Org-N[2]	Cl	P	Na	K	Ca	Mg	Mn	B
	Concentration in mg/liter											
Hardwood 1" Control												
Forest Floor Pans	6.3	0.12	5.0	3.3	0.9	0.818	1.6	10.3	11.6	1.3	0.06	0.34
6" Tension Lysimeter	7.6	0.09	0.4	1.7	2.3	0.053	3.8	14.2	46.9	34.2	0.10	0.12
24" Tension Lysimeter	7.3	0.09	0.4	1.5	2.1	0.030	3.0	7.4	16.3	12.5	0.21	0.05
48" Tension Lysimeter	7.1	0.09	0.3	1.5	2.5	0.044	9.5	6.0	11.2	10.9	0.13	0.05
Red Pine Control Plots												
Forest Floor Pans	7.5	0.14	6.0	4.0	1.0	0.477	2.8	9.3	13.7	1.8	0.13	0.06
1" Control												
6" Tension Lysimeter	7.6	0.14	0.6	2.4	1.9	0.052	3.9	11.9	35.5	20.8	0.07	0.10
24" Tension Lysimeter	7.6	0.08	0.2	0.7	4.7	0.056	2.2	6.8	32.9	19.5	0.03	0.05
48" Tension Lysimeter	7.2	0.08	0.1	1.0	1.3	0.051	1.4	1.8	3.3	1.4	0.02	0.03
2" Control												
6" Tension Lysimeter	7.1	0.05	1.3	[1]	8.0	0.079	7.0	7.8	23.5	12.5	0.73	0.12
24" Tension Lysimeter	7.1	0.09	0.7	1.1	15.5	0.024	6.0	5.7	18.2	8.5	0.07	0.04
48" Tension Lysimeter	6.7	0.06	1.8	1.5	6.1	0.056	5.1	5.1	5.6	2.6	0.06	0.04
Old Field 2" Control												
6" Tension Lysimeter	7.2	0.15	0.4	1.9	1.3	0.045	1.9	7.2	14.6	5.1	0.03	0.05
24" Tension Lysimeter	7.2	0.09	0.4	0.9	1.7	0.032	1.2	8.9	8.2	3.6	0.03	0.04
48" Tension Lysimeter	6.9	0.07	0.3	1.0	0.7	0.039	1.4	5.4	1.3	0.6	0.04	0.04

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[1] Insufficient samples volume for complete analyses.

[2] Includes ammoniacal nitrogen.

Table A-32. Chemical Composition of Sewage Effluent Applied on Original Forestry Experimental Plots (Farm Woodlot Site) During the Period 4/9/68 to 11/12/68.

	Range		
Constituent	Min	Max	Average
	ppm	ppm	ppm
pH	6.3	8.1	7.7
MBAS	0.0	2.4	0.6
Nitrate-N	0.0	12.6	5.1
Organic-N[1]	2.5	38.5	19.9
Phosphorus	2.015	16.193	8.455
Potassium	12.1	23.8	18.6
Calcium	17.9	33.4	26.4
Magnesium	8.9	17.0	13.3
Sodium	27.4	65.6	40.2
Chloride	16.7	77.1	46.4
Boron	0.23	0.69	0.37
Manganese	0.03	0.20	0.12
NH_4-N	4.5	25.5	13.2

[1] Includes ammoniacal nitrogen.

Table A-33. Average Concentration in Percolate Samples and in the Sewage Effluent for the Original Forestry Plots (Farm Woodlot Site) During the Irrigation Period 4/9/68 to 11/12/68.

	pH	MBAS	NO_3-N	NH_4-N	Org-N[2/]	Cl	P	Na	K	Ca	Mg	Mn	B
						Concentration in mg/liter							
Effluent Quality	7.7	0.59	5.1	13.2	19.9	46.4	8.455	40.2	18.6	26.4	13.3	0.12	0.37
Hardwood 1-inch													
Forest Floor Pans	7.1	0.17	14.8	4.6	7.3	32.6	6.808	27.4	18.5	25.6	10.3	0.11	0.23
6" Tension Lysimeter	7.5	0.7	10.9	1.4	1.8	51.9	0.166	38.6	10.3	30.8	25.7	0.03	0.28
24" Tension Lysimeter	7.1	1/	10.0	3.0	1/	70.2	0.388	1/	1/	1/	1/	1/	1/
48" Tension Lysimeter	8.0	1/	8.0	3.0	1/	38.6	0.222	1/	1/	1/	1/	1/	1/
Red Pine 1-inch													
Forest Floor Pans	7.1	0.17	15.9	5.2	7.0	33.1	6.501	27.5	14.0	25.1	10.0	0.10	0.20
6" Tension Lysimeter	7.5	0.08	18.7	1.3	2.3	46.0	0.562	39.8	11.4	40.7	30.3	0.03	0.27
12" Tension Lysimeter	7.9	0.08	19.8	1.3	1.7	37.9	0.262	40.2	15.3	74.5	30.1	0.06	0.20
24" Tension Lysimeter	7.8	1/	6.1	0.6	3.6	35.9	0.253	36.7	7.6	28.9	15.8	0.02	0.20
48" Tension Lysimeter	7.6	1/	2.7	0.7	2.0	53.0	0.089	28.7	6.6	35.9	25.6	0.03	0.09
Red Pine 2-inch													
Forest Floor Pans	7.5	0.17	15.8	5.5	8.0	42.0	7.678	33.5	16.3	26.2	11.8	0.19	0.24
6" Tension Lysimeter	7.3	0.15	21.8	1.6	2.2	49.2	1.007	42.2	16.9	36.7	22.9	0.14	0.32
12" Tension Lysimeter	7.8	1/	32.7	3.0	2.5	72.9	0.134	52.6	34.0	98.6	54.8	0.46	0.32
24" Tension Lysimeter	7.1	1/	17.6	0.7	0.7	88.2	0.109	57.7	5.7	17.5	7.5	0.06	0.24
48" Tension Lysimeter	6.8	0.11	19.9	0.6	0.8	88.5	0.044	61.1	5.1	6.9	3.9	0.07	0.12

Table A-33. Continued.

	pH	MBAS	NO_3-N	NH_4-N	Org-N2/	Cl	P	Na	K	Ca	Mg	Mn	B
						Concentration in mg/liter							
Old Field 2-inch													
6" Tension Lysimeter	7.5	0.21	4.8	0.8	1.6	32.9	0.275	28.3	2.4	22.8	13.3	0.03	0.26
12" Tension Lysimeter	8.0	1/	6.1	1.0	1.5	46.4	0.073	43.1	12.6	53.1	34.4	0.03	0.27
24" Tension Lysimeter	7.8	1/	4.9	1.1	2.1	35.3	0.125	29.2	7.0	42.9	25.9	0.03	0.27
48" Tension Lysimeter	7.4	0.16	3.7	0.7	1.4	30.9	0.053	30.2	4.0	11.4	7.7	0.38	0.18

1/ Insufficient sample volume for complete chemical analyses.

2/ Includes ammoniacal nitrogen.

Table A-34. Average Concentration of Constituents in the Percolate Samples of the Original Forestry Control Plots (Farm Woodlot Site) During the Period 4/9/68 to 11/12/68.

	pH	MBAS	NO_3-N	NH_4-N	Org-N[2/]	Cl	P	Na	K	Ca	Mg	Mn	B
	Concentration in ppm												
Hardwood 1" Control													
Forest Floor Pans	6.7	0.11	6.8	2.4	4.7	1.7	0.773	0.7	10.5	16.4	1.4	0.08	0.06
6" Tension Lysimeter	7.6	0.12	0.4	0.9	1.4	2.8	0.064	1.1	2.3	20.9	13.7	0.05	0.03
24" Tension Lysimeter	7.4	0.09	0.2	0.5	0.9	1.8	0.044	2.7	3.6	12.8	10.0	0.13	0.03
48" Tension Lysimeter	7.1	0.21	0.1	3.3	4.0	2.5	0.106	6.3	5.1	8.8	7.5	0.49	0.04
Red Pine Control													
Forest Floor Pans	6.6	0.12	8.6	2.7	5.0	1.7	0.762	0.7	7.7	18.4	1.6	0.06	0.05
1" Control													
6" Tension Lysimeter	7.9	0.08	0.5	1.1	1.0	0.2	0.024	2.0	5.8	21.0	9.4	0.04	0.06
24" Tension Lysimeter	7.8	0.05	0.2	0.9	0.6	1.1	0.013	1/	1/	1/	1/	1/	1/
48" Tension Lysimeter	7.5	0.07	0.2	0.6	0.3	0.4	0.134	1.7	2.0	3.0	1.2	0.03	0.02
2" Control													
48" Tension Lysimeter	6.9	0.06	1.6	0.1	0.5	13.7	0.015	11.9	5.4	3.5	0.9	0.02	0.04
Old Field 2" Control													
24" Tension Lysimeter	6.5	0.04	0.2	0.5	0.8	1.0	0.122	1.8	0.4	7.5	2.3	0.01	0.02
48" Tension Lysimeter	6.9	0.11	0.2	0.4	0.6	1.4	0.040	1.5	3.2	1.9	0.5	0.01	0.03

[1/] Insufficient sample volume for complete chemical analyses.

[2/] Includes ammoniacal nitrogen.

Table A-35. Average Concentration of Percolate Samples and of Sewage Effluent in the New Red Pine - 2 inches Per Week Area. 1965 and 1966.

	pH	MBAS	NO_3-N	Org-N[1/]	P	K	Ca	Mg	Na	Cl	Mn	B
					Concentration in mg/1							
				Irrigation Period - 4/20/65 to 11/16/65								
Effluent Quality	7.7	1.07	6.2	2.8	10.129	15.2	29.7	15.3	35.8	47.2		
6" Tension Lysimeter	7.7	.07	13.8	0.8	1.452	10.7	23.2	5.0	36.3	52.8		
24" Tension Lysimeter	6.8	0.10	11.0	0.7	.823	6.9	16.1	3.8	28.9	45.8		
48" Tension Lysimeter	7.0	.08	14.5	0.3	.834	6.0	11.9	2.1	17.0	30.9		
				Irrigation Period - 4/5/66 to 11/15/66								
Effluent Quality	7.7	0.38	6.0	4.9	9.383	17.0	29.2	16.9	34.7	51.2	0.06	0.33
Forest Floor Pans	7.3	0.228	13.9	3.9	8.102	16.3	27.7	15.1	34.2	50.0	0.07	0.26
6" Tension Lysimeter	6.7	0.06	18.6	1.1	.076	11.7	14.2	6.8	34.6	53.8	0.26	0.20
24" Tension Lysimeter	6.8	0.07	14.7	1.3	.064	5.3	13.2	5.6	32.6	50.2	0.22	0.10
48" Tension Lysimeter	6.8	0.07	8.9	1.2	.058	6.6	8.8	4.0	22.2	32.2	0.26	0.10

[1/] Includes ammoniacal nitrogen.

Table A-36. Average Concentration in Percolate Samples and in Sewage Effluent for the New Red Pine - 2 inches Per Week Area. 1967 and 1968.

	pH	MBAS	NO_3-N	NH_4-N	Org-N[1/]	P	K	Ca	Mg	Na	Cl	Mn	B
	Concentration in mg/1												
Irrigation Period - 4/18/67 to 10/31/67													
Effluent Quality	7.7	0.47	4.9	-	4.1	8.721	14.6	21.6	11.2	36.7	45.4	0.10	0.41
6" Tension Lysimeter	6.3	0.08	16.7	-	1.1	0.132	11.2	12.1	8.4	33.1	37.4	0.19	0.19
24" Tension Lysimeter	6.5	0.09	14.5	-	1.2	0.049	6.0	8.7	4.2	34.6	43.9	0.09	0.10
48" Tension Lysimeter	6.5	0.09	11.1	-	1.7	0.163	8.2	4.9	3.2	24.0	30.2	0.13	0.11
Irrigation Period - 4/9/68 to 11/12/68													
Effluent Quality	7.8	0.38	3.6	17.2	22.1	9.656	16.4	25.6	12.9	41.3	46.0	0.15	0.35
6" Tension Lysimeter	7.5	0.07	23.9	1.3	1.6	0.609	13.7	51.6	32.6	42.3	42.8	0.17	0.26
12" Tension Lysimeter	8.0	0.02	24.6	1.5	1.5	0.384	12.8	73.5	36.1	43.6	43.2	0.15	0.22
24" Tension Lysimeter	7.6	0.11	21.3	1.0	1.4	0.131	10.4	57.1	32.1	48.4	41.3	0.06	0.21
48" Tension Lysimeter	7.0	0.07	16.1	1.1	1.1	0.247	8.1	13.0	9.1	37.0	34.4	0.23	0.17

[1/] Includes ammoniacal nitrogen.

Table A-37. Average Concentration of Percolate Samples and of the Sewage Effluent in the New Gamelands Area. 1966 and 1967.

	pH	MBAS	NO_3-N	Org-N1/	P	K	Ca	Mg	Na	Cl	Mn	B
					Concentration in mg/l							
					Irrigation Period - 5/18/66 to 12/26/66							
Effluent Quality	7.7	0.55	5.8	4.0	9.779	18.4	32.8	18.9	38.2	51.5	0.08	0.35
Forest Floor Pans	7.1	0.19	15.4	4.2	7.241	17.8	24.4	21.8	32.5	43.4	0.12	0.24
6" Tension Lysimeter	7.1	0.08	12.5	1.8	0.248	17.9	11.1	8.1	36.0	53.1	0.63	0.14
24" Tension Lysimeter	6.8	0.06	14.9	1.3	0.029	8.6	12.3	3.1	37.7	49.6	1.19	0.16
48" Tension Lysimeter	6.6	0.06	10.6	1.2	0.041	9.4	10.8	5.2	28.9	51.1	1.11	0.10
					Irrigation Period - 1/2/67 to 12/25/67							
Effluent Quality	7.6	0.36	5.7	4.6	8.435	14.9	22.0	11.2	36.4	48.1	0.13	0.34
Forest Floor Pans	7.2	0.18	14.9	2.9	7.287	15.3	22.8	9.8	19.0	36.8	0.19	0.25
6" Tension Lysimeter	7.0	0.10	16.9	2/	0.113	11.0	14.9	7.7	31.5	41.1	0.13	0.22
24" Tension Lysimeter	6.2	0.08	20.4	1.6	0.057	11.2	20.4	13.7	31.7	41.7	0.26	0.17
48" Tension Lysimeter	6.4	0.09	19.2	1.4	0.063	6.7	18.4	11.6	34.1	42.5	0.48	0.16

1/ Includes ammoniacal nitrogen.

2/ Insufficient samples.

Table A-38. Average Concentration of Percolate in the Hardwood Control Plot at the New Gamelands Site. 1966 and 1967.

	pH	MBAS	NO_3-N	Org-N[1]	P	K	Ca	Mg	Na	Cl	Mn	B
					Concentration in mg/1							
						1966						
Forest Floor Pans	6.4	0.11	8.5	4.6	0.590	10.5	19.8	1.7	1.1	1.6	0.23	0.06
6" Tension Lysimeter	6.8	0.02	0.2	1.5	0.076	5.8	11.1	1.7	1.3	1.3	0.30	0.03
24" Tension Lysimeter	7.2	0.03	0.5	1.0	0.091	6.2	13.6	3.3	6.7	2.4	0.05	0.05
48" Tension Lysimeter	6.8	0.03	0.1	1.5	0.058	6.4	8.0	4.9	2.2	13.7	0.18	0.04
						1967						
6" Tension Lysimeter	6.7	0.08	10.6	[2]	0.049	5.1	9.2	2.7	1.4	1.1	0.42	0.04
24" Tension Lysimeter	7.5	0.03	0.5	1.0	0.223	10.2	4.7	21.5	1.5	0.8	0.24	0.07
48" Tension Lysimeter	6.8	0.07	1.4	1.1	0.068	7.0	3.2	4.6	4.0	7.7	0.06	0.04

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[1] Includes ammoniacal nitrogen.

[2] Insufficient samples.

Table A-39. Average Concentration in Percolate Samples and Sewage Effluent for the Hardwoods New Gamelands Area which Received 2 Inches of Effluent Per Week During the Period 1/1/68 to 12/31/68 and for a Nearby Control Area.

	pH	MBAS	NO$_3$-N	NH$_4$-N	Org-N[1/]	Cl	P	Na	K	Ca	Mg	Mn	B
						Concentration - mg/1							
						Irrigated Area							
Effluent Quality	7.7	0.56	4.2	16.8	20.9	49.5	9.081	42.6	14.9	24.3	11.8	0.19	0.33
Forest Floor Pans	7.3	0.33	13.5	10.0	13.6	47.3	8.997	40.4	15.4	26.0	11.9	0.25	0.28
6" Tension Lysimeter	7.3	0.10	22.3	1.3	2.0	46.8	0.452	38.6	11.8	41.7	22.7	0.08	0.25
12" Tension Lysimeter	7.8	0.06	21.9	2.9	3.1	43.2	2.955	37.0	11.7	48.6	27.9	0.12	0.23
24" Tension Lysimeter	6.7	0.09	26.0	0.9	1.3	45.7	0.129	37.9	8.5	25.4	15.1	0.13	0.17
48" Tension Lysimeter	7.1	0.11	25.9	1.0	1.2	49.5	0.116	37.7	11.0	26.3	14.1	0.63	0.19
						Control Area							
Forest Floor Pans	6.9	0.13	6.9	2.8	5.6	1.8	0.725	1.4	8.6	17.1	1.4	0.71	0.05
6" Tension Lysimeter	6.9	0.07	0.1	0.4	1.2	1.9	0.020	1.0	3.3	11.7	5.1	0.66	0.04
12" Tension Lysimeter	8.1	[2/]	0.2	0.9	1.4	5.8	0.041	2.0	5.2	28.6	16.8	0.13	0.05
24" Tension Lysimeter	6.8	0.20	0.2	0.1	1.7	0.6	0.050	1.3	5.6	14.0	2.1	0.07	0.06
48" Tension Lysimeter	6.8	0.08	0.1	0.3	1.1	1.2	0.071	2.8	4.6	6.4	3.0	0.03	0.03

[1/] Includes ammoniacal nitrogen.

[2/] Not analyzed.

Table A-40. Average Concentration of Constituents in the Effluent and in the Percolate at Various Soil Depths on the Plot which Received 4 Inches Per Week During 1965.

Soil depth inches	MBAS Concn mg/1	Nitrate N Concn mg/1	Organic[1/] N Concn mg/1	P Concn mg/1	K Concn mg/1	Ca Concn mg/1	Mg Concn mg/1
Effluent Quality	1.61	7.6	2.7	10.383	16.3	29.5	14.8
6	0.35	7.3	1.2	2.053	13.1	17.5	12.6
12	0.27	5.7	1.5	1.311	7.6	6.5	4.7
24	0.23	4.2	1.1	1.471	8.4	6.2	2.5
26	0.20	5.3	1.1	1.441	7.9	5.2	5.2
48	0.16	2.3	1.1	1.700	6.6	8.9	6.3
60	0.16	4.8	0.8	1.480	7.2	8.3	4.9
72	0.23	5.2	0.9	1.621	7.5	3.7	2.2

[1/] Includes ammoniacal nitrogen.

Table A-41. Average Concentration of Constituents in the Percolate Samples Collected from Pan Lysimeters Located in the Hardwood Plot which Received 4 Inches of Effluent Per Week During the Period 4/5/66 to 11/17/66

	pH	MBAS	NO_3-N	Org-N[1/]	P	K	Ca	Mg	Na	Cl	Mn	B
							Concentration in mg/1					
Effluent Quality	7.6	0.40	7.5	5.0	9.520	17.5	28.5	17.3	33.4	46.3	0.05	0.36
Soil Depth - inches												
6	7.5	0.40	11.1	2.7	5.347	14.7	26.1	17.9	34.0	40.4	0.12	0.28
12	7.1	0.16	9.0	2.3	0.816	10.6	12.3	11.6	41.5	65.5	0.09	0.29
24	6.9	0.11	9.3	1.6	0.193	7.7	6.5	3.3	38.3	67.8	0.19	0.24
26	6.9	0.08	9.1	1.3	0.044	7.5	5.1	5.4	42.5	79.5	0.13	0.20
48	7.0	0.09	9.1	1.1	0.018	6.3	10.6	6.8	37.1	86.1	0.03	0.08
60	7.0	0.08	11.1	1.0	0.040	6.3	6.9	4.1	44.0	91.2	0.10	0.08
72	6.9	0.12	9.5	1.0	0.047	5.2	3.4	2.0	36.5	82.1	0.07	0.07

[1/] Includes ammoniacal nitrogen.

Table A-42. Average Concentration of Constituents in the Percolate Samples Collected from Pan Lysimeters Located in the Hardwood Plot Which Received 4 Inches of Effluent Per Week During the Period 4/18/67 to 10/31/67

	pH	MBAS	NO_3-N	Org-N[1/]	Cl	P	Na	K	Ca	Mg	Mn	B
					Concentration in mg/1							
Effluent Quality	7.0	0.45	6.3	4.5	46.8	7.682	35.4	13.9	20.3	10.6	0.06	0.34
Soil Depth - inches												
6	7.2	0.21	8.6	2.6	35.9	4.043	31.2	14.4	21.8	12.3	0.13	0.27
12	7.1	0.17	7.9	2.7	47.8	2.430	37.7	12.8	16.4	12.6	0.10	0.30
24	6.9	0.10	5.1	1.4	54.1	0.124	38.2	6.9	5.8	3.8	0.20	0.28
36	6.8	0.11	9.0	1.4	65.2	0.062	41.7	7.0	5.5	6.3	0.18	0.24
48	7.3	0.11	3.4	1.7	66.6	0.219	43.6	4.4	16.6	8.6	0.03	0.13
60	7.1	0.12	7.8	1.3	69.6	0.793	40.8	5.2	6.8	3.9	0.15	0.12
72	6.9	0.10	8.3	1.3	56.9	0.072	39.3	6.9	2.5	1.8	0.00	0.13

[1/] Includes ammoniacal nitrogen.

Table A-43. Mean Nutrient Element Concentration of the Soil Samples Collected in 1963, 1964, and 1965 in the Red Pine 1-inch Treatment and Control Plots

Depth	N	Cl	K	Ca	Mg	Mn	B	Na
	%	mg/1	me/100gm	me/100gm	me/100gm	mg/1	mg/1	me/100gm
				TREATMENT				
1963 (Fall)								
1.0	0.088	10.5	0.51	1.2	0.5	122	0.4	0.29
2.0	0.021	24.4	0.34	1.9	0.7	48	0.2	0.12
3.0	0.014	15.5	0.42	1.3	0.7	48	0.6	0.12
4.0	0.014	20.8	0.52	1.0	0.9	54	0.4	0.14
5.0	0.010	10.1	0.59	0.7	0.7	46	0.6	0.14
1964 (Spring)								
0.5	0.094	50.7	0.21	0.7	0.3	172	0.4	0.22
1.0	0.032	10.5	0.31	1.2	0.2	88	0.4	0.25
2.0	0.026	68.3	0.29	1.7	0.7	54	0.4	0.21
3.0	0.024	49.7	0.37	0.8	0.7	42	0.4	0.11
1965 (Fall)								
0.5	0.121	20.1	0.79	2.3	1.0	18	1.0	0.45
1.0	0.075	27.5	0.71	1.4	0.4	17	1.0	0.48
2.0	0.030	22.1	0.73	2.2	0.8	9	1.0	0.39
3.0	0.019	18.4	0.99	2.5	1.8	3	1.0	0.29
4.0	0.026	13.5	0.76	2.2	2.3	4	0.8	0.25
5.0	0.013	1.7	0.94	1.5	1.7	6	1.2	0.18
				CONTROL				
1963 (Fall)								
1.0	0.07	12.7	0.29	1.3	0.2	126	0.2	0.17
2.0	0.017	4.7	0.45	2.0	0.7	36	0.4	0.13
3.0	0.014	8.6	0.42	0.9	1.1	48	0.4	0.10
4.0	0.014	9.8	0.42	0.9	1.4	36	0.6	0.16
5.0	0.008	2.8	0.51	0.8	1.4	42	0.4	0.12
1964 (Spring)								
0.5	0.103	8.6	0.45	0.7	0.2	198	0.4	0.19
1.0	0.042	13.3	0.45	0.8	0.2	78	0.6	0.10
2.0	0.023	8.2	0.51	1.4	0.8	31	0.4	0.14
3.0	0.020	6.6	0.39	0.8	1.2	38	0.4	0.15

Table A-43. Continued.

Depth	N	Cl	K	Ca	Mg	Mn	B	Na
	%	mg/l	me/100gm	me/100gm	me/100gm	mg/l	mg/l	me/100gm
1965 (Fall)								
0.5	0.148	13.8	0.53	2.1	0.2	34	0.6	0.19
1.0	0.079	10.1	0.47	1.6	0.3	21	0.6	0.12
2.0	0.024	21.7	0.64	3.5	1.0	8	0.8	0.19
3.0	0.016	22.5	0.61	1.3	0.9	8	0.8	0.18
4.0	0.018	17.8	0.61	0.8	1.1	10	0.6	0.18
5.0	0.018	6.2	0.67	0.8	1.1	10	0.8	0.12

Table A-44. Mean Chemical Element Concentration of the Soil Samples Collected in 1963, 1964, and 1965 in the Red Pine 2-inch Treatment and Control Plots.

Depth	N	Cl	K	Ca	Mg	Mn	B	Na
	%	mg/1	me/100gm	me/100gm	me/100gm	mg/1	mg/1	me/100gm
				TREATMENT				
1963 (Fall)								
1.0	0.070	12.4	0.42	1.3	0.4	80	0.6	0.31
2.0	0.031	29.1	0.47	2.2	0.8	42	0.6	0.28
3.0	0.023	39.6	0.53	1.3	1.4	48	0.6	0.17
4.0	0.028	19.2	0.67	1.2	1.4	42	0.4	0.15
5.0	0.026	16.9	0.51	1.1	1.8	56	0.4	0.12
1964 (Spring)								
0.5	0.168	13.9	0.79	4.4	1.6	86	0.8	0.31
1.0	0.053	53.9	0.96	1.3	0.4	96	0.6	0.23
2.0	0.025	21.8	0.39	1.6	0.6	66	0.4	0.30
3.0	0.068	30.5	0.34	1.1	0.9	50	0.4	0.27
1965 (Fall)								
0.5	0.128	12.6	0.88	3.8	1.8	17	1.0	0.45
1.0	0.059	18.8	0.56	1.3	0.7	19	0.8	0.43
2.0	0.030	20.6	0.45	2.1	0.5	10	0.6	0.44
3.0	0.025	23.9	0.37	1.5	0.9	14	0.6	0.50
4.0	0.018	29.1	0.34	0.9	1.0	9	0.4	0.41
5.0	0.019	30.7	0.39	0.9	1.1	10	0.6	0.39
				CONTROL				
1963 (Fall)								
1.0	0.075	4.2	0.39	1.2	0.3	98	0.6	0.14
2.0	0.026	4.3	0.29	2.2	0.7	40	0.6	0.17
3.0	0.019	4.1	0.29	0.9	0.7	32	0.4	0.14
4.0	0.020	5.2	0.29	0.5	0.6	34	0.4	0.16
5.0	0.015	11.8	0.42	0.3	0.4	26	0.6	0.09
1964 (Spring)								
0.5	0.115	31.7	0.42	0.9	0.2	196	0.4	0.09
1.0	0.084	14.8	0.45	1.5	0.2	74	0.6	0.20
2.0	0.034	43.9	0.39	1.9	0.6	46	0.6	0.16
3.0	0.020	9.3	0.50	1.1	1.0	48	0.6	0.15

Table A-44. Continued.

Depth	N	Cl	K	Ca	Mg	Mn	B	Na
	%	mg/1	me/100gm	me/100gm	me/100gm	mg/1	mg/1	me/100gm
1965 (Fall)								
0.5	0.122	9.7	0.64	1.7	0.2	44	0.8	0.16
1.0	0.045	7.3	0.54	1.9	0.5	18	0.6	0.16
2.0	0.023	12.3	0.62	1.6	0.9	22	0.8	0.17
3.0	0.018	14.7	0.53	0.6	0.7	16	0.6	0.12
4.0	0.020	22.5	0.53	0.4	0.6	16	0.8	0.15
5.0	0.012	15.4	0.51	0.4	0.5	30	0.8	0.22

Table A-45. Mean Nutrient Element Concentration of the Soil Samples Collected in 1963, 1964, 1965 in the Open Area 2-inch Treatment and Control Plots.

Depth	N	Cl	K	Ca	Mg	Mn	B	Na
	%	mg/1	me/100gm	me/100gm	me/100gm	mg/1	mg/1	me/100gm
				TREATMENT				
1963 (Fall)								
1.0	0.072	27.6	0.64	1.7	0.5	44	1.0	0.25
2.0	0.022	30.6	0.62	1.8	0.9	20	0.8	0.22
3.0	0.017	16.5	0.64	1.0	0.9	26	0.8	0.10
4.0	0.014	17.7	0.56	0.8	0.9	62	0.8	0.09
5.0	0.016	17.8	0.51	0.6	0.8	18	0.8	0.09
1964 (Spring)								
0.5	0.118	21.9	0.53	2.1	0.6	78	0.4	0.24
1.0	0.053	18.0	0.19	1.6	0.5	50	0.2	0.28
2.0	0.025	49.7	0.31	1.5	0.7	42	0.2	0.29
3.0	0.019	33.9	0.26	0.8	0.7	38	0.2	0.25
1965 (Fall)								
0.5	0.149	13.2	0.97	3.7	1.4	6	1.0	0.35
1.0	0.048	9.9	0.53	1.3	0.5	6	1.0	0.30
2.0	0.021	20.3	0.47	2.2	0.8	5	0.6	0.43
3.0	0.016	23.0	0.56	1.7	1.1	5	0.8	0.29
4.0	0.016	18.8	0.47	1.2	1.0	5	0.6	0.28
5.0	0.013	13.9	0.56	0.7	0.6	5	1.0	0.27
				CONTROL				
1963 (Fall)								
1.0	0.088	7.7	0.37	1.4	0.3	72	0.6	0.09
2.0	0.016	2.6	0.51	1.9	0.8	20	0.6	0.14
3.0	0.012	2.3	0.51	1.1	1.3	22	0.6	0.19
4.0	0.010	7.5	0.45	0.9	1.6	18	0.6	0.18
5.0	0.010	9.6	0.45	0.9	1.5	18	0.6	0.16
1964 (Spring)								
0.5	0.130	13.5	0.37	1.3	0.3	74	0.4	0.19
1.0	0.057	4.2	0.37	1.5	0.3	44	0.4	0.11
2.0	0.051	19.1	0.29	1.9	0.9	22	0.2	0.20
3.0	0.025	11.7	0.29	0.8	1.0	44	0.2	0.17

Table A-45. Continued.

Depth	N	Cl	K	Ca	Mg	Mn	B	Na
	%	mg/1	me/100gm	me/100gm	me/100gm	mg/1	mg/1	me/100gm
1965 (Fall)								
0.5	0.107	1.5	0.62	0.8	0.3	9	0.8	0.13
1.0	0.048	2.8	0.62	1.5	0.3	6	0.8	0.13
2.0	0.028	7.9	0.42	1.5	0.5	6	0.4	0.13
3.0	0.018	15.2	0.53	0.7	0.5	8	0.8	0.13
4.0	0.018	7.1	0.51	0.7	0.4	6	0.8	0.14
5.0	0.014	11.4	0.59	0.7	0.4	5	0.8	0.09

B. Wells and Springs in Centre County Sampled by the Project

No.	Name	Location
1	Earl Tressler	R. D. 1, Bellefonte
2	Kermit Rockey	R. D. 1, Bellefonte
3	Robert Snetsinger	R. D. 1, Bellefonte
4	Bernard Crust	R. D. 1, Bellefonte
5	William Spearly	R. D. 1, Bellefonte
6	Harry Spearly	R. D. 1, Bellefonte
7	Basil Frank	R. D. 1, Bellefonte
8	Walter Richner	R. D. 1, Bellefonte
9	Edith Taylor	R. D. 1, Bellefonte
10	John Blair	R. D. 1, Bellefonte
11	Clarence Zeigler	R. D. 1, Bellefonte
12	Jerald Duck	R. D. 1, Bellefonte
13	Dennis Riordan	R. D. 1, Bellefonte
14	Steven Williams	Port Matilda, R. D.
15	John W. Myers	Port Matilda, R. D.
16	Kenneth Watson	Port Matilda, R. D.
17	Ralph E. Myers	Port Matilda, R. D.
18	Lake Wall	Port Matilda, R. D.
19	James Wilson	Port Matilda, R. D.
20	Charles Sellers	Port Matilda, R. D.
21	John Hokanson	R. D. 1, Bellefonte
22	James Bruss	R. D. 1, Bellefonte
23	Adolph Reed	Port Matilda, R. D.
24	Wayne Showers	Port Matilda, R. D.
25	Charles Stem	Port Matilda, R. D.
26	Benjamin Heim	R. D. 1, Bellefonte
27	Allen Wolford	Houserville Rd., State College
28	Clifford Quick	Box 41, Lemont
29	William Hersh	Big Hollow Rd., State College
30	Briarly Manor	R. D. 1, Bellefonte
31	Lester Myers, Jr.	Port Matilda, R. D.
32	Andrew Lentvorsky	Port Matilda, R. D.
33	Robert Delafield	Rock Rd., State College
34	Joseph Stover	R. D. 1, Bellefonte
35	Wayne Burnett	Puddintown Rd., State College
36	W. E. Clark, Jr.	Box 556, State College
37	Franklin King	Port Matilda, R. D.
38	David Ammerman	R. D. 1, Bellefonte
39	Robert Keith	Big Hollow Rd., State College
40	Charles Taylor	R. D. 1, Bellefonte
41	Marvin Swatsworth	Big Hollow Rd., State College
1935	Merle L. Wilson	R. D. 1, Bellefonte
1936	Raymond Fetzer	R. D. 1, Bellefonte
1937	Martin W. Schein	Rock Rd., State College

No.	Name	Location
Sp. 1	Thompson Spring	State College
Sp. 2	Bathgate Spring	Lemont Water Supply
Sp. 3	Musser Spring	Port Matilda, R. D.
Sp. 4	Benner Spring	Pa. Fish Hatchery
Sp. 5	Paradise Spring	Pa. Fish Hatchery
Sp. 6	Big Spring	Bellefonte Water Supply
Un. 2	Penn State Univ.	University Park
Un. 3	Penn State Univ.	University Park
Un. 14	Penn State Univ.	University Park
Un. 16	Penn State Univ.	University Park
Un. 17	Penn State Univ.	University Park
Un. 24	Penn State Univ.	University Park
Un. 26	Penn State Univ.	University Park
St. 1	Buffalo Run Stream	Benner Township

C. Chemical Procedures Used in Wastewater Project

EFFLUENT AND WATER SAMPLES

Organic Nitrogen (includes NH_4)

Procedure:

Transfer an aliquot of the sample (50 ml. <10 ppm NH_4-N; 10 ml - to 60 ppm NH_4-N) into a 125 ml. erlenmeyer flask. Add 5 ml. of sulfuric acid-selenium oxychloride solution and swirl. Heat gradually to boiling on a hot plate under a hood and digest until clear. Cool. If the solution is not colorless add 2 drops of 10% perchloric acid and shake immediately. Heat again until colorless but do not boil. Cool. Transfer to a 100 ml. volumetric flask and make up to volume. Shake flask and transfer 10 ml. to a 50 ml. volumetric flask. Neutralize with NaOH (approximately 2 ml. of 9N NaOH). Shake, add 2 ml. gum arabic, make up to 35 to 40 ml. volume and shake again. Add 2 ml. Nessler reagent, make up to 50 ml. volume and shake.

After 10 minutes read the transmittance at 425 mu wavelength on a Spectronic 20.

Standards:

Transfer 10 ml. of 0.0, 1.0, 2.0, 4.0 and 6.0 ppm N working stock solutions into 50 ml. volumetric flasks. This gives standards of 0.0, 0.2, 0.4, 0.8 and 1.2. Use same procedure as for samples to develop Nessler color after neutralizing with NaOH.

Stock NH_4 Solution-100 ppm N

Weigh out 0.1910 grams of reagent grade NH_4Cl into a small beaker. Transfer to 500 ml. volumetric flask, dissolve and make up to volume with H_2O. Transfer to suitable glass container. This makes 100 ppm standard.

Working Stock Solution:

Place approximately 50 ml. of H_2O in each of five 100 ml. volumetric flasks. Add 5 ml. of the sulfuric acid selenium oxychloride solution cautiously, swirl, and allow to cool. Add 0, 1, 2, 4, and 6 ml of the 100 ppm N Standard NH_4 solution to the five flasks respectively. Bring the volume up to 100 ml. with H_2O and shake. Transfer 10 ml from each flask to separate 50 ml. volumetrics, neutralize with NaOH then develop Nessler color as with samples.

Reagents:

9N NaOH - Add 360 grams of U.S.P. grade NaOH per liter H_2O, cautiously. Stir and cool.

Gum Arabic Solution - Add 1% gum arabic by weight to H_2O and shake. 5 grams/500 ml. H_2O.

Sulfuric acid-selenium oxychloride solution - Add 1.5 ml. of selenium-oxychloride solution per liter of conc. H_2SO_4, shake.

Nessler Reagent - Dissolve 300 gm of KOH in 400 ml. distilled H_2O and allow to cool. Dissolve 60 gm $HgCl_2$ in 600 ml. distilled H_2O (Apply heat until dissolved). Dissolve 123.5 gm Kl in 500 ml. distilled H_2O in a 2000 ml. volumetric flask. Add the $Hg\ Cl_2$ solution to the Kl solution until red precipitate begins to form; then add $Hg\ Cl_2$ dropwise until red precipitate does not dissolve by swirling. Add 1.5 gm of Kl to the solution and the red precipitate should redissolve; shake well. Add the KOH solution, shake well, cool, make up to volume. Transfer to a brown bottle and keep in cool dark place. Centrifuge sub-aliquots if the reagent is not clear.

Ammonium Only

Procedure:

Transfer an aliquot of the sample (5 ml. <10 ppm; 1 ml. 10-60 ppm) into a 50 ml. volumetric flask. Add 0.6 ml. of 9N. NAOH. Add 2 ml. of gum arabic solution. Add water to make volume 35 to 40 ml. and shake. Add 2 ml. of Nessler reagent and add water to bring up to 50 ml. volume. Shake samples and read transmittance at 425 mu setting on Spectronic 20 after 10 minutes.

ABS (alkyl benzene sulfonate) - MBAS (methylene blue active substance)

Transfer a 100 ml sample to a 250 ml separatory funnel. If less than 100 ml of sample is used make up to 100 ml with H_2O. Add 1 ml of $4NH_2SO_4$, mix by swirling. Add 10 ml of chloroform and 25 ml of methylene blue solution. Shake for 30 seconds. Allow chloroform and water phases to separate. Excessive agitation may cause emulsion trouble.

Drain off chloroform into a second separatory funnel. Repeat extraction two more times. If blue color in water phase becomes faint add 25 ml more of methylene blue solution.

To the chloroform in the second separatory funnel add 50 ml of wash solution. Shake 30 seconds. Allow chloroform to separate out and draw off through cotton plug in small funnel into a 100 ml volumetric flask. Extract wash solution twice more with 10 ml portions of chloroform. Rinse stem of separatory funnel and cotton plug in funnel with about 5 ml of chloroform. Dilute to 100 ml mark with chloroform, and mix well.

Make up 100 ml standards from 0-1.3 ppm, treat same as unknowns.

Measure absorbance at 652 mu on Spectronic 20.

ABS Reagents

Standard alkyl benzene sulphonate (ABS) solution (1,000 ppm)

2.0534 gm (Association of American Soap and Glycerine Producers, New York) ABS dissolved in 1,000 ml.

Four Normal Sulfuric Acid

Pour 56 ml of conc. H_2SO_4 into 500 of H_2O in a liter Pyrex flask, mix, cool.

Chloroform - use ACS Reagent grade.

Methylene blue reagent

Dissolve 0.1 gm methylene blue in 100 ml of distilled water. Transfer 30 ml of this solution to a 1-liter flask. Add 500 ml of distilled water, 6.8 ml of conc. H_2SO_4 and 50 gm of monosodium dihydrogen phosphate monohydrate, $NaH_2PO_4 \cdot H_2O$. Shake until solution is complete. Dilute to 1-liter.

Wash solution

Add 6.8 ml conc. H_2SO_4 to 500 ml. of distilled water in a 1-liter volumetric flask. Then add 50 gm of NaH_2PO_4 H_2O and shake until solution is complete. Dilute to the 1-liter mark with H_2O.

Nitrate Nitrogen

Turn nitrate ionalyzer on and allow to warm up for about 20 min. before making readings. Check electrodes to be certain that they are full of filling solutions. Pour out approximately 25 ml of water sample into a 50 ml beaker. Standardize ionalyzer with 10 ppm and 100 ppm $N\text{-}NO_3$ standards. Temperature must be set for both standards and samples. Standards and samples should be read while being stirred with magnetic stirrer. Instrument should be rechecked with standards after every 20 samples.

Spectrographic Analysis for K, Ca, Mg, Mn, B and Na

Transfer 100 ml of composite sample to 125 ml evaporating dish unless the composite sample contains less than 100 ml and then transfer 50 ml of sample. Evaporate sample in an oven set at 105°c. Samples are then ready to be taken up in lithium-HCl buffer and run on arc spectrograph. The samples are analyzed for K, Ca, Mg, Mn, B, Na. Code sheets accompany samples when they are transferred to the spec. lab.

Orthophosphate Phosphorus

Transfer an aliquot of water containing 0 to 40 ug of phosphorus to a 150 ml beaker and add distilled H_2O to make volume 50 ml. Make standards of 0.0, 0.2, 0.4, 0.6, 0.8 ppm in 50 ml total volume. (Add 1, 2, 3, 4 ml of 10 ppm stock P to 49, 48, 47, 46 ml of distilled H_2O respectively plus the 2 beakers containing 50 ml distilled H_2O). Add 2 ml of sulfomolybdic acid to each standard and each sample and stir well. Add 0.25 ml of stannous chloride to each standard and sample except for one of the 0.0 standards, which is used to set 100% transmittance on the Spectronic 20, and stir immediately. The samples should be read between 6 and 12 minutes after developing with stannous chloride. Determine transmittance of samples at 690 mu on Spectronic 20.

Sulfomolybdic Acid Solution - Add 310 ml of concentrated H_2SO_4 cautiously to 400 ml of distilled H_2O in a 1000 ml beaker. Stir and allow to cool. To 180 ml of distilled H_2O in another beaker add 25gm of ammonium molybdate and stir. After acid has cooled, add molybdate solution, stir and allow to cool. Transfer to an acid bottle, make up to 1000 ml. mark, shake, and store in a dark place.

Stannous Chloride Solution - Weigh out 1.25gm of stannous chloride ($SnCl_2 \cdot 2H_2O$) in a 30 ml beaker and dissolve in 5 ml of concentrated HCl. If solution is not clear, heat gently over a flame. Transfer solution to a 50 ml. volumetric flash, make up to volume, and shake. Store in dark and make up fresh every week.

Standard Phosphorus Solution: 500 ppm P

Dissolve 2.1950gm of dried KH_2PO_4 in about 400 ml of water in a 1000 ml volumetric. Add 5 ml of conc H_2SO_4 to help preserve the standard. Dilute to 1000 ml, place in storage bottle, and keep refrigerated.

Phosphorus working standard: Transfer 10 ml of 500 ppm P to a 500 ml volumetric, make up to volume, and shake.

pH

Pour out water sample into 1 oz paper cup (about 3/4 full). The pH meter is set with pH_4 and pH_7 buffer solutions. Temperature of the water samples is checked and the meter is set. The samples are then read and recorded.

Chloride

Transfer 10ml of water sample into a 30ml beaker. Transfer 10ml distilled H_2O into 30ml beaker for blank at beginning of run and after every 30 samples. Transfer 20 ml 100ppm chloride standard solution into 30ml beaker to be run with each blank. Add 10ml of buffer solution to samples and blanks (buffer is already included in standard). Add 1ml of gel reagent to all blanks, standards, and samples. High titration rate should be used for titrating water samples. If silver electrode is cut to renew, an extra standard should be run to condition the new silver wire. If microammeter does not return to 0, all electrodes should be thoroughly cleaned and rinsed. Titrator should warm up 20 min. before titration is begun.

Buffer solution - Add 400 ml distilled H_2O to a 1000ml volumetric flask. Add 200 ml of glacial acetic acid and 12.8 mls of conc nitric acid; make up to volume and shake.

Gel reagent - Dissolve 0.62gm of gel reagent into each 100ml of distilled H_2O. Heat if necessary. Keep refrigerated.

Standard - transfer 5mls of 10,000ppm Cl stock standard to a 1000ml volumetric flask. Add 100ml acetic acid and 6.4ml (concentrated) nitric acid. Make up to volume and shake.

Stock Solution of Chloride: Weigh out 8.2413 gm of reagent grade NaCl into a 50ml beaker. Dissolve in distilled H_2O and transfer to a 500ml volumetric flask. Make up to volume, shake, and transfer to a storage bottle.

SOIL SAMPLES

Exchangeable Cations

Weigh out 5 gm. of dry, sieved soil into a 50 ml. centrifuge tube. Add 33 ml 1N NH_4OA_c, shake in a mechanical shaker for 5 min. and centrifuge for 5 min. at 2000 rpm. Decant supernatant through a Whatman No. 2, 12.5cm filter paper into a 125 ml. porcelain evaporating dish. Repeat extraction with two additional 33 ml portions of NH_4OA_c. Soil must be resuspended in extraction solution before shaking in mechanical shaker. Evaporate total extract to dryness in oven set at 105^{o}c. Have residue taken up in spectrograph buffer and Ca, Mg, K, Na, Mn, B determined on the spectrograph.

Ammonium Acetate solution: Add 77.08 gm of NH_4OA_c - per liter of solution. The solution is then adjusted to pH 7.0 by adding acetic acid or ammonium hydroxide.

Exchangeable Hydrogen

A 10 gm soil sample is weighed out into a 125 ml erlenmeyer flask. Add 25 ml of the Ba Cl_2 buffer solution and shake for 1/2 hrs. The suspension is then filtered through a Buchner funnel fitted with Whatman No. 42, 55 mm paper. The soil is completely transferred with 25 ml more of the buffer solution. The soil in the funnel is then further leached with 100 ml of $BaCl_2$ replacement solution.

The combined filtrates are titrated with standard 0.1N HCl to an end point with bromcresol green-methyl red indicator, the color being standardized against a blank titration of similar volumes of the 2 extraction solutions.

0.5N$BaCl_2$ - buffer solution - add 62.5 g. of $BaCl_2$ $2H_2O$ and 25 ml of triethnolamine per liter of solution.

0.5N $BaCl_2$ - replacer solution - Add 62.5 g. $BaCl_2 2H_2O$ and 2.5 ml. of buffer solution per liter of replacer solution.

Bromcresol green - 0.5% in ethanol

Methyl red - 0.2% in ethanol

Soil Organic Matter

Transfer a weighed quantity of soil (ground to pass a 0.5 mm sieve) containing 10 to 25 mg of organic carbon. (Use 0.5g for 1st foot, 2 gm for 2nd foot, and 3 gm for 3rd through 5th foot on waste water project soils) into a 250 ml erlenmeyer flask. Add 10 ml of N potassium dichromate and then 20 ml of concentrated sulfuric acid, directing the stream into the solution. Immediately swirl vigorously for 1 min. and let the flask stand on a sheet of asbestos for about 30 minutes. Then add 100 ml of water, 10 ml of phosphoric acid, swirl and allow to cool. Add 4 drops of ferroin indicator. (1,10-phenanthroline, ferrous sulfate complex)

Proceed with the titration as follows: Add the ferrous sulfate solution until the solution begins to change from a reddish-brown to a grayish color then add the ferrous sulfate dropwise until a permanent gray color exists. If more than 8 ml of the available 10 ml of potassium dichromate is reduced, the determination should be repeated with less soil. The ferrous sulfate is standardized against a blank of 10ml of $NK_2Cr_2O_7$ plus all other reagents.

1N Potassium dichromate solution - Dissolve 49.04 gm of reagent grade $K_2Cr_2O_7$ in water and dilute to 1 liter.

o.5N Ferrous ammonium sulfate solution - Dissolve 196.08 gm of $Fe(NH_4)_2$-$(SO_4)_2$ $6H_2O$ plus 40 ml. of concentrated H_2SO_2 per liter of solution.

Soil pH

The soil pH is determined on a 1:1 soil to water mixture. Ten grams of air dry, sieved (passing 10 mesh) soil is measured into a 1 oz paper cup. Ten milliliters of distilled H_2O is then added to the soil and stirred. The soil is allowed to stand for 15 min. and then stirred again. After standing another 15 min. the soil is stirred and immediately the pH is read on any suitable pH meter.

Soil Chloride

A 2gm sample of dry, sieved soil is weighed out into a 125 ml erlenmeyer flask. Twenty ml of 0.05N NH_4NO_3 is added to the flask and shaken on a mechanical shaker for 5 minutes. The suspension is then filtered through Whatman No. 2, 12.5cm filter paper into a 50 ml beaker. A 10ml aliquot of the filtrate is then transferred to a 30 ml beaker; 10 ml of buffer solution and 1ml of gel reagent are added. The samples are then titrated on the Aminco-Cotlove Chloride titrator. Run standard and blank before samples are started and after every 30 samples. Standard: Transfer 2.5 ml of 10,000 ppm stock chloride solution into a 1000ml volumetric flask. Make up to volume with 0.05N NH_4NO_3 and shake. Use 10 ml of this solution for standard, add 10ml buffer solution, and 1ml gel reagent.

Buffer solution: Add 400 ml dist H_2O to a 1000ml volumetric flask. Add 200 mls acetic acid and 12.8 mls nitric acid; make up to volume with H_2O and shake.

Gel reagent: Dissolve 0.62g.gel reagent in 100 ml distilled H_2O. Keep refrigerated.

Stock Chloride Solution: Weigh out 8.2413gm of regent grade NaCl into a 50 ml beaker. Dissolve and transfer to a 500ml volumetric flask. Make up to volume, shake, and transfer to a storage bottle.

Extractable Soil Phosphorus

A 2.85 gm sample of crushed, sieved (2mm) soil is weighed out into a 50 ml bottle or test tube. 20 ml of extracting solution ($0.03N \cdot NH_4F$ in $0.025N \cdot HCl$) is added and the bottle is stoppered and shaken for 1 minute. The suspension is immediately filtered on a moist Whatman No. 42 filter paper in a funnel. 2 ml of the clear filtrate is transferred to a colormeter tube, then 5 ml of water is added and mixed. The 2 ml of molybdate is added and mixed followed by addition of 1 ml of freshly diluted stannous chloride with immediate mixing. After 5-6 minutes and before 15-20 minutes the blue color is read at 690 mu on a Spectronic 20.

The ammonium molybdate reagent was made by dissolving 15 grams of ammonium molybdate in 300 ml of distilled water warmed to 50°C. After cooling add 350 ml of 10.0N·HCl slowly with rapid stirring. The solution is then diluted to 1000 ml and stored in an amber, glass stoppered bottle.

The stannous chloride stock solution is made by dissolving 10 grams of stannous chloride in 25 ml of concentrated HCl. It is kept in a dark, tightly stoppered bottle. For each day's run a freshly diluted solution was prepared by adding 1 ml of the stock solution to 330 ml of freshly boiled, cooled, distilled water.

PLANT SAMPLES

Total Nitrogen in Plant Material

Weigh out and transfer a 0.25gm plant sample into a 125ml Pyrex erlenmeyer flask. Add 5ml of salicylic-sulfuric acid mixture and allow to stand 30 minutes, swirling occasionally to insure complete contact of acid and plant material. Add 4 drops of sodium thiosulfate solution, swirl, add 5ml of selenium oxychloride-sulfuric acid solution. Mix thoroughly. Heat gradually to boiling on a hot plate under a hood and digest until clear. If the solution is not colorless, add 2-3 drops of 10% perchloric acid and swirl. Heat again slowly until solution is colorless but do not boil.

Transfer solution to a 100ml volumetric flask, fill to volume and shake. Transfer a 1ml (for corn-0.5ml for Reed Canary Grass) aliquot of the solution to a 50ml volumetric flask. Neutralize with NaOH (approximately 0.8ml of 9N NaOH). Fill flask to 35-40ml with distilled H_2O. Add 2 ml of gum arabic; swirl. Add 2ml of Nessler reagent, make up to volume and shake. Read samples and standards at 425 mu wave length on Spectronic 20 or similar photometer.

Calculation of Total Nitrogen

1ml = Dilution Factor: 1:20,000 (Corn)

0.5ml = Dilution Factor: 1:40,000 (Reed Canary Grass)

thus: ppmN x 2.0 = TN in % N (Corn)
ppmN x 4.0 = TN in % N (Reed Canary Grass)

Reagents:

Salicylic-sulfuric acid solution - Add 32gm of salicylic acid per liter concentrated H_2SO_4.

Sodium thiosulfate solution - 70.45gm $Na_2S_2O_3 \cdot 5H_2O$ per 100ml of distilled H_2O.

Selenium oxychloride-sulfuric acid - 1.5ml of selenium oxychloride per liter concentrated H_2SO_4.

Plant Ashing Procedure

Samples are ashed in vitrex crucibles. Vitrex crucibles must be washed in alkanox solution, rinsed, dipped in 0.1 N HCl and rinsed thoroughly with distilled H_2O. The crucibles must then be dried, with care being taken to avoid dust settling into the crucibles. One gm. of the plant material, to the nearest .0001 of a gm., is then weighed into each crucible which is placed in a steel and asbestos tray. The grays are placed in the muffle furnace, the exhaust hood is started, and the muffle furnace heated to 485°C. Samples are ashed for 8 hrs. and then cooled gradually to room temperature.

After cooling, the ashed samples are removed from the muffle furnace and transferred to plastic bottles with assistance of silver plated funnel and camel hair brush. Caution should be exercised to avoid breezes. Samples are then ready for spec analysis by the method of Baker, et al (81).

Chloride Determination in Plant Material

Weigh 0.50gm of plant material into a 125ml erlenmeyer flask. Add 20ml of 0.05 N NH_4NO_3. Digest on steam bath for one hour, filter while hot through a filter paper (Whatman No. 2) into a 100 ml volumetric flask. Wash filter and residue with three additional 20ml portions of hot 0.05N NH_4NO_3. Cool filtrate to room temperature make up to volume with distilled water, shake to mix. Transfer a 10ml aliquot to Aminco-Cotlove titrator beakers, add 10ml of nitric-acetic acid buffer and 1 ml of gelatin and proceed with titration.

Select standard chloride concentration and switch position on titrator to keep titration time less than 100 seconds. Use 0.05 N NH_4NO_3 in making up standards and blanks.

Standard - Add 5 ml of 10,000ppm Cl Stock solution to 400ml of 0.05N NH_4NO_3 in a 500 ml volumetric flask. Make up to volume and shake. Use 10ml standard + 10ml of buffer solution for each standard.

Blank - Add 100ml dist H_2O to 400ml 0.05N NH_4NO_3. Stir. Use 10ml of this solution + 10ml buffer solution for each blank.